RISKS OF 3-D PRINTING PENS

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This project is done through Worcester Polytechnic Institute. Specifically, it is the Interactive Qualifying Project. All personnel remained anonymous and responses confidential unless otherwise stated. The opinions shared in this proposal are our own and do not represent the opinions of WPI or the Consumer Product Safety Commission. This information is solely used for academic research.

ABSTRACT

3-D printing pens have been increasing in popularity over the past few years and are easily accessible with a simple online order. Only being out for about 8 years, there is limited research on the risks relating to the pens and the filaments they use. In this project, we analyzed published data on filaments used in 3-D printing pens and potential risks they may pose, such as from Volatile Organic Compounds (VOCs) and Ultrafine Particles (UFPs). Using this collected data, we came up with recommendations for people to use 3-D printing pens with reduced exposure. Additionally, a testing plan was created to explore the exposure of a 3-D printing pen user under both typical-use and high-end scenarios.

EXECUTIVE SUMMARY

Introduction

3-D printing pens are products that are rising in popularity in both home and school settings. These settings mixed with some models of 3-D printing pens being targeted towards children caught the eye of the Consumer Product Safety Commission (CPSC) staff. In the introduction we discuss the rise in popularity, why the CPSC is interested in the product, and potential hazards.

Laying the Foundation

The origin of the 3-D printing pen is a sub-product of a process that has been around for decades know as additive manufacturing. The most common filaments used in 3-D printing pens are then described giving details on their physical attributes.

A few pens are compared to show the variation in cost, skill level, and filament material that 3-D printing pens use.

Use of 3-D printing pens in schools was explored as a location of interest. The use and potential benefits of using a 3-D printing pen with children is discussed. Higher-level usage of 3-D printing pens was also explored.

There are potential health risks of 3-D printing pens. The main exposures explored were changes in indoor air quality due to emissions of UFPs and VOCs from melting filaments. Since the pen is a handheld device, the user can be exposed to those emissions. Children could be especially vulnerable to these emissions and potentially could have associated acute or chronic health effects.

Methodology

Various methods were used to collect qualitative data related to 3-D printing pen use.

This section begins by providing an overview on the research guidelines we followed when collecting qualitative data. The three main methods were: interviews and surveys, a literature review, and usability and practicality test.

Findings

This section includes the results found from each of our methods. Results from complementary research, including a label review and an online user review, are also presented in this section.

This section also discusses the health and safety fact sheet our team developed, which provides safety recommendations to 3-D printing pen users.

Conclusions

This section begins with a discussion on the implications of the project, more specifically those implications for the CPSC staff. We also discuss issues that we experienced throughout the IQP process. This section also contains ideas for future work including product testing.

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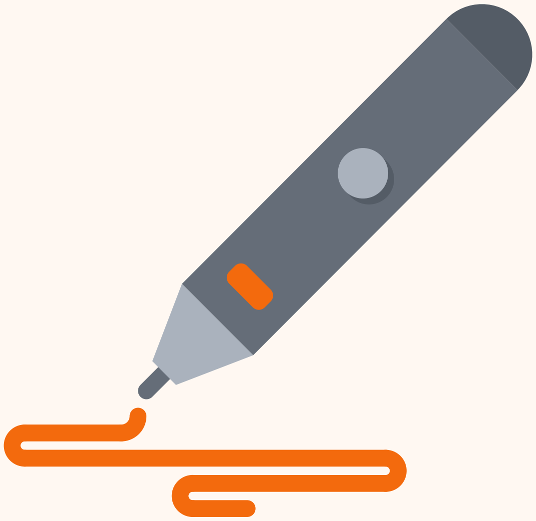
INTRODUCTION



3-D printers are becoming readily available for consumers as they migrate out of manufacturing labs and into schools and homes (Uses for 3D Printing 2015-2020, n.d.). In particular, 3-D printing pens, which are handheld 3-D printing devices, have become more popular due to them being marketed to children and teachers for use in classrooms (3D Printing Pen | The World's First and Best, n.d.); (Junior 3D Pen for Kids Bundle - MYNT3D, n.d.). However, the safety of 3-D printing pens has not been fully evaluated for consumers. At most, the pens include a choking hazard warning label, but due to its nature being a handheld 3-D printer, some possible hazards include various bodily injuries like burns and exacerbation of respiratory illnesses. The Consumer Product Safety Commission (CPSC) staff has identified the hazards associated with 3-D printers, but 3-D printing pens bring a new set of concerns as the proximity to the user's body is much closer. The users are also more vulnerable due to their young age.

The CPSC exists to protect "consumers and families from products that pose a fire, electrical, chemical, or mechanical hazard."(CPSC.Gov, n.d.). The CPSC seeks to prevent any unreasonable injuries or deaths from consumer products. They lower the potential for risk by ensuring manufacturers adhere to product safety requirements and provide the public free access to various resources, such as product safety information. Moreover, the CPSC has centers where manufacturers and importers test their products to ensure certain safety requirements are met.

The CPSC staff run their own tests on products that could prove problematic, which allows them to find specific hazards that were not previously addressed. This allows them to release proper safety guidelines and recall products. For the 3-D printing pens, CPSC staff has limited knowledge of the specifics of the hazards and prevention methods associated with them. Therefore, the focus of this project was to explore use, hazards, and the components of 3-D printing pens.

The goals for this project were as follows:

1. assess the safety of using 3-D printing pens particularly for school work
2. make recommendations for safe practices when using pens to the CPSC staff and consumers
3. provide preliminary usage data for 3-D printing pens and methods for future testing

To achieve these goals, we first gathered data on pen usage in schools both locally and nationally. This data was used to create experiments to understand consumer exposure of hazards associated with 3-D printing pens. Second, we conducted usability and practicality experiments of these products with the goal of identifying potential risks. The findings of our project include literature review of previous studies on 3-D printing pens, health and safety fact sheet, preliminary usage data, and directions for future IQP projects.

LAYING THE FOUNDATION

Variations in the Printing Process and Hardware

3-D printing is a form of additive manufacturing (AM.) This type of manufacturing is exactly as it sounds. Materials are built upon one another (generally in a vertical layering process). There are seven basic AM process categories. (Shahrubudin et al., 2019)

Figure 1: Basic Additive Manufacturing (AM) Process Categories

3-D printing pens fall under the category of ME, more specifically a modified version of fused deposition modeling (FDM) or fused filament fabrication (FFF). FDM is a trademarked term and used for more industrial printers, whereas FFF is a non-trademarked term and is used for more hobbyist desktop printers.

The 3-D printers themselves vary as much as the different types of printing processes. 3-D printers' contrast with one another based on their size and price. Some printers are more than three meters long, whereas some are as small as a typical ink pen. The larger, more expensive equipment is mainly used in industrial settings, such as printing optimized medical devices for hospitals. On the opposite end, the smaller, cheaper printers are in the form of 3-D printing pens. These are used in recreational and educational settings because they are more attainable and cost efficient. For example, the cheapest desktop 3-D printers retail around $200, while the cheapest 3-D printing pen costs $35.

Although these variations provide a similar end product (Cardoso et al., 2020), there are still key differences. These differences appear in working environments where consumers use 3-D printing. For instance, a large company that deals with medical devices would have a premium printer with many different filaments. They would also have adequate ventilation and safety measures to prevent any injuries. On the other hand, the average consumer does not need that advanced scale of printer, so most instead opt for a smaller, less expensive version. Individual consumers tend to purchase a desktop 3-D printer, which are available in different sizes.

Some are as big as 29″ x 30″ x 25″ (Fusion 3 Design, n.d.), or as small as 17″ x 22″ x 19″ (LulzBot Mini Desktop 3D Printer: Amazon.Com: Industrial & Scientific, n.d.). However, the variations in printer size do not compensate for two major flaws: those being the significant amount of time required to complete a printing operation, and the lack of transportability of ordinary 3-D printers.

Fortunately, 3-D printing pens are available for consumers that desire a more casual, time-efficient 3-D printing experience. These printers are also easily transportable, as they are handheld and do not weigh more than 100 grams (Kuusito-Lukkari, 2021).

The first 3-D printing pen was released in February of 2013 by the company 3Doodler. This product started on Kickstarter.com, a crowdfunding source focused on creativity. Essentially

Kickstarter.com is a website that allows the public to financially support creator's inventions while simultaneously providing the creators a platform to get their inventions funded and turned into an actual product.

The concept of a 3-D printing pen started on this website, and it was one of the most successful products because of its uniqueness. 3Doodler marketed their product as a way to express one's creativity and it is "A Pen For All Ages". (3D Printing Pen | The World's First and Best, n.d.). Because the consumer age range is so broad, 3Doodler created three styles of pen for the varying target audiences, which are ages 6-13, ages 14+, "professional", and educators for grades K-12. The brand intends for their product to be used in an educational and home setting. One example of this can be found on 3Doodler's website, where teachers are able to purchase different "Learning Packs" (3D Printing Pen | The World's First and Best, n.d.). These Learning Packs include six or twelve pens, hundreds of strands of filament, lesson plans, and challenge cards (which depict models of real-world mechanisms for students to better understand how they work).

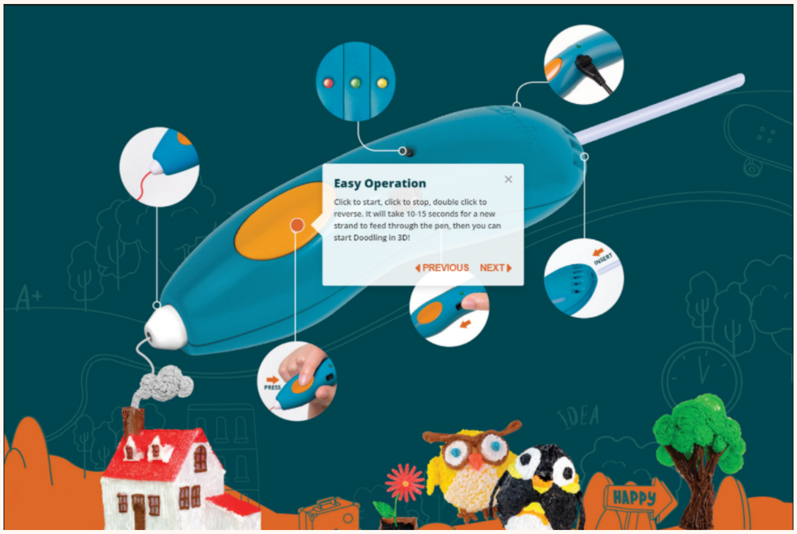


Figure 2: Pen schematic (Source: O'Neal, 2016)

"Filament" is the raw, thread-like material used to 3-D print objects. There are numerous filaments to pick from because each serve a different purpose. Some filaments are known for their durability while others are known for finish. However, not all filaments can be used with 3-D printing pens. The filaments that are most applicable for pen use (does not include brand specific filaments, e.g. 3Doodler Eco-Plastic) are as follows: Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Polycaprolactone (PCL), and Polyethylene Terephthalate Glycol (PETG).

Most Common 3-D Printing Pen Filaments

Acrylonitrile Butadiene Styrene (ABS)

- Best known for its toughness and impact resistance
- Smooth, shiny surface finish
- Non-biodegradable polymer and not created from a renewable source (petrochemical compounds)
- Comes with a warning to print with ventilation because an odor is emitted while in use
- Extruder temperature range of 220-250 °C, depending on the specific chemical composition ("ABS," n.d.)

Polylactic Acid (PLA)

- One of the most popular filaments on the market because of its versatility, printability, and eco friendliness
- Durable and smooth, shiny surface finish
- Biodegradable polymer produced from agricultural sources, which means it is created from a renewable source of raw materials (Sin & Tueen, 2019)
- Extruder temperature range of 190-220 °C, depending on the specific chemical composition ("PLA," n.d.)

Polycaprolactone (PCL)

- Best known for its "kid safe," low print temperature
- Smooth, matte surface finish while still being durable
- Biodegradable polymer and can be recycled. However, like ABS, it is made from a nonrenewable source of raw materials. (Sin & Tueen, 2019)
- Softens in water greater than 50 °C and can be reshaped. ("PCL," n.d.)
- Extruder temperature range of 115-145 °C, depending on the specific chemical composition

Polyethylene Terephthalate Glycol (PETG)

- A "modified version of PET (polyethylene terephthalate) mixed with glycol which makes it less brittle, clearer, and more durable and impact resistant." (3dsourced, 2020)
- Smooth glossy finish
- Non-biodegradable oil-based polymer
- Extruder temperature range of 230-250 °C, depending on the specific chemical composition ("PETG," n.d.)

3-D Printing Pen Comparison

As mentioned previously, 3-D printing pens have become more popular in the market due to them being marketed to teachers and children for use in classrooms. Three pen brands have dominated the 3-D printing pen market on Amazon: 3Doodler, Mynt3d, and Scrib3D. Below is a chart that compares attributes of specific pen models from the three brands. Most of the categories contain basic information, including cost per pen, recommended age/experience, filament compatibility, and extra items included with the pen. Information on heat risk is based on a predetermined scale. This scale can be seen in the figure caption below.

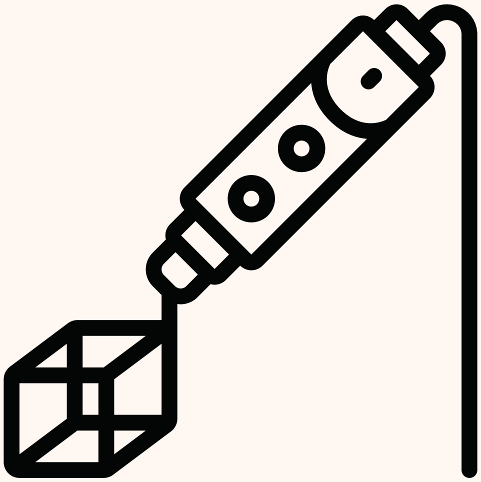
Pen Brand	3Doodler			Mynt3d			Scrib3d	
Pen Model	Start+	Create+	Pro+	Pen Junior 2	Pen Super	Pen Pro	P1	ADV
Amazon Cost (without tax or shipping)	$49.06	$79.99	$199.99	$39.99	$39.99	$59.99	$29.99	$49.99
Age/Experience	6-13 years old	14+ years old	"creative professionals"	6-12 years old	"artists and engineers of all ages"	anyone who wants to "take your design projects to greater heights"	14+ years old	14+ years old
Filament Compatability: filaments recommended for the pens	Eco-Plastic	PLA, ABS, Flexy and Wood Plastic Filaments	PLA, ABS, Wood, Metal, and Nylon Plastic Filaments	PCL	PLA and ABS	any 1.75mm filament and melts within temperature range	PLA and ABS	PLA and ABS
Heat Risk (Temperature): scaling critera is below	Low	High	High	Low	High (140-230 °C)	High (130 - 230 °C)	High (160 - 235 °C)	High (160 - 235 °C)
Extras Included in Package	DoodlePad/Doodlemat, 2 Mixed-color Packs of Start plastics (48 Strands), Micro-USB Charger & Activity Guide	3 packs of 3Doodler 3 mm plastic refills, power adaptor, maitenance tools, ultimate guide to doodling, instruction manual	Nozzle Set, Mini DoodlePad, Unblocking Tool, 6 Filament Refill Packs, Product Manual and Quick Start Guide, International Adapters	User manual, 3 rolls of MYNT3D PCL plastic, Starter stencils and USB cable	3 colors of ABS plastic filament A/C adapter, screwdriver	manual, 3 rolls ABS filament, USB cord, AC adapter, nozzle replacement tools	manual, A/C adapter, free stencil guide, 3 colors (15 meters) of PLA plastic.	3 colors (15 meters) of PLA plastic, power adapter, step-by-step manual, and a free stencil guide

Table 1: Comparison Chart for Most Popular 3-D Printing Pen Brands: All data was collected from Amazon.com (Amazon.Com. Spend Less. Smile More., n.d.), Mynt3d.com (MYNT3D, n.d.), 3Doodler.com (3D Printing Pen | The World's First and Best, n.d.). The criteria for the heat risk scale is as follows: HIGH indicates the extruder tip is exposed and between 130-235 °C or LOW indicates the extruder tip is enclosed and between 80-130 °C

3-D Printing Pens for Educational Purposes

Recently, there has been a push for Science, Technology, Engineering and Math (STEM) to be integrated in many classrooms across the nation. Technologies and engineering expose children to complex topics on a basic level, such as programming a robot or learning how to 3-D print. 3-D printing pens are a technology that provide a hands-on experience that improves a child's observational and problem-solving skills, concentration, and creativity (Chen & Cheng, 2021). A child must concentrate on adding layer by layer when using a pen. They also need to understand the physical dimensions of the product they are designing, which requires much thought and effort. A 3-D printing pen user is also not limited by a two-dimensional plane, such as a piece of paper, or pre-designed shapes and pieces. Children also have the freedom to design whatever they want with 3-D printing pens, and they can let their creative minds flow.

One example is the use of 3-D printing pens in an elementary math class. The pens give students the opportunity to make 3-D models of shapes, such as cylinders, pyramids, or spheres. They see "geometries (and mathematics) as concepts 'to think and act with', and 'to inquire and invent with'" (Ng & Ferrara, 2020). In the end the students learn how the pen works, thereby gaining technical literacy, and acquire a fuller understanding of fundamental math concepts.



3-D printing pens have been used at Worcester Polytechnic Institute (WPI). A staff member in the Advanced Technology and Prototyping department originally invested in the Mynt3d Pen Pro for a workshop on how to post-process a student's 3-D printed parts. The pen was utilized to fill in the under extruded parts of the design and make the product more aesthetically pleasing. Subsequently, they found another use for the 3-D printing pen in the creation of a 3-D printed replica of the school mascot statue for 2021 Commencement.

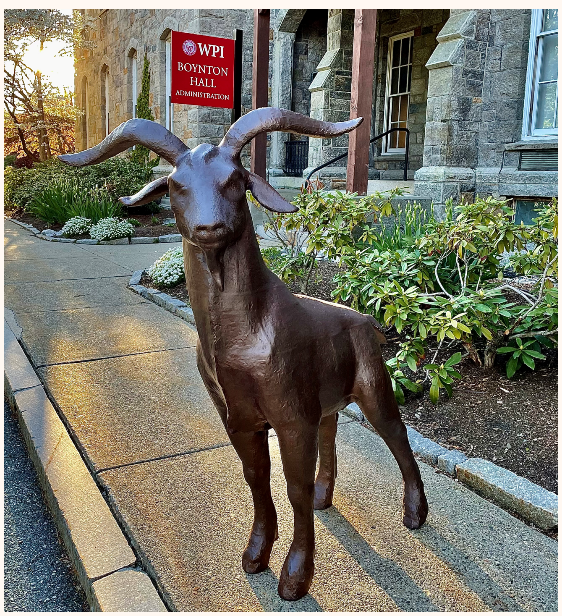


Figure 3: 3-D printed mascot (Source: Adam Murrison)

In this project, the pen was useful for the friction welding needed to put all the 3-D printed parts together. For both instances, the pen was not the main tool used to create either project. It acted as a supplementary tool to fix small areas on the project, rather than being used for the main workload. However, there were some instances where a 3-D printing pen was used as the main tool in an operation. One situation consisted of cosplayers at WPI that used 3-D printing pens to add intricate designs to their costumes.

The two examples of pen usage in schools previously discussed highlight the benefits of 3-D printing pens as an educational tool. The incorporation of 3-D printing pens in more schools will provide students with an appropriate introduction to 3-D printing at a much lower price than a desktop 3-D printer. In spite of all these positive and productive uses in education, 3-D printers have downsides.

Figure 4: 3-D printed mascot before painting (Source: Adam Murrison)

Health Risks with 3-D Printing Pens

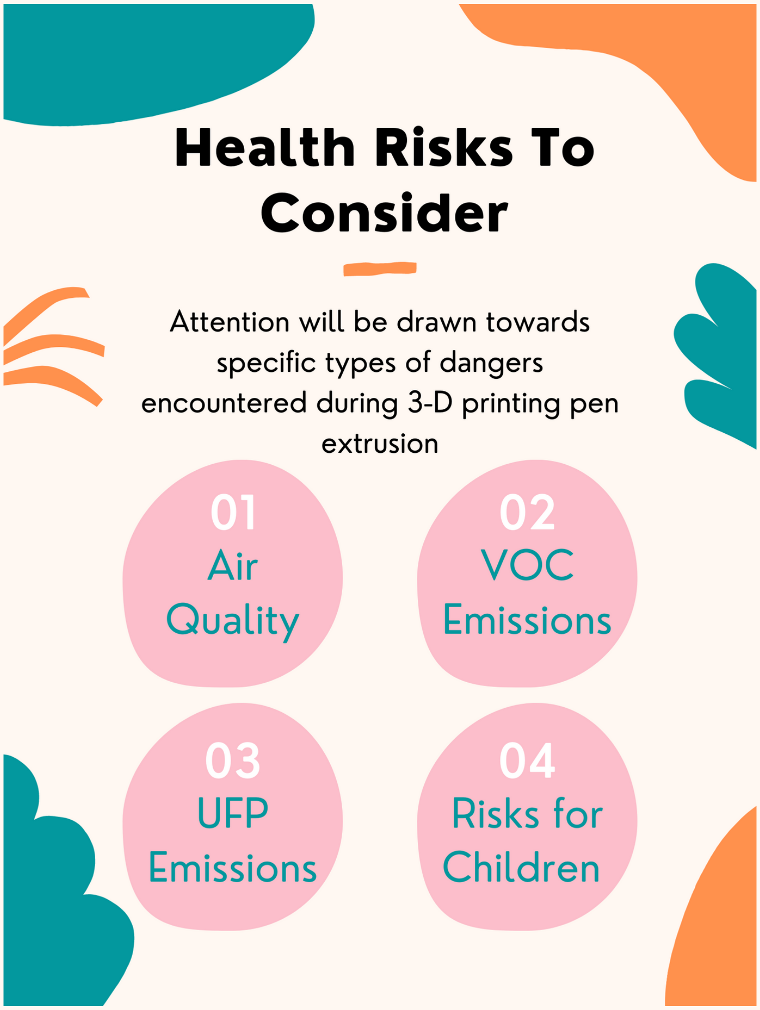


Figure 5: Health Risks To Consider

The following sections will highlight the health risks with 3-D printing pens. We will explain the following topics: indoor air quality importance, Volatile Organic Compound (VOC) emissions, Ultrafine Particle (UFP) emissions, and potential risks for children.

Indoor Air Quality Importance

Indoor air quality is an important aspect of a healthy environment. Indoor air quality problems were more apparent in the past than they are today (Jones, 1999). The Environmental Protection Agency (EPA), has "found that levels of several organics average 2 to 5 times higher indoors than outdoors. During and several hours immediately after certain activities, such as paint stripping, levels may be 1,000 times background outdoor levels." (United States Environmental Protection Agency [US EPA], 2014). This statistic notes that activities involving chemical emissions influence the room's indoor air quality and therefore require proper ventilation to regulate the indoor air quality. Given that 3-D printing pens are almost always used indoors and involve the heating and melting of plastic filament which contains chemicals, they likely present a risk to the user.

The Indoor Air Quality Scientific Findings Resource Bank conducted a report on the correlation between ventilation rates in various settings and the health of the population. One of the primary conclusions was that "higher ventilation rates will reduce indoor concentrations of a broad range of indoor-generated air pollutants but also increase indoor concentrations of some pollutants from outdoor air." (Indoor Air Quality Scientific Findings Resource Bank Berkeley Lab, n.d.) The indoor air quality depends not only on the filtration systems in the ventilation, but also the concentration of the outdoor air pollutants. Furthermore, the overarching issue is that no federally enforceable standards have been set for VOCs in non-industrial settings (US EPA, 2014). This is most concerning as 3-D printers and printing pens are easily accessible and they emit VOCs into the indoor environment during and after use. The government cannot keep track of every person who buys a 3-D printer (or other devices that release VOCs) so it is hard to ensure that the building the consumer is using the product in is properly ventilated.

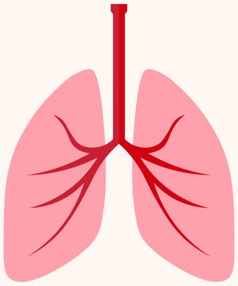
VOC Emissions

3-D printing produces potentially hazardous pollutants, one type being VOCs. "VOCs are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects." (US EPA, 2014) VOCs can be found in the air normally, however, the concentration around the area of printing increases to higher levels depending on the material used (Park et al., 2021). The increased level of concentration within the print area potentially results in more VOCs being inhaled.

There are a variety of types of VOCs that are emitted during 3-D printing; some are problematic due to their association with health risks. In one experiment, VOCs were collected from several prints with a variety of material being printed (Davis et al., 2019). The types of VOCs, including Benzaldehyde, Styrene, and Formaldehyde, were recorded along with their prevalence. Of the collected samples, a variety of them could be seen listed on Indoor Air Quality Standards. The CPSC staff lists symptoms and side effects for VOCs (CPSC, 2016). Some symptoms are mild conditions such as headaches, dizziness, and fatigue, whereas others are far more severe. These include nasal congestion, epistaxis, and hearing loss among many others.

Ultrafine Particle (UFP) Emissions

Ultrafine Particles (UFPs) are another pollutant that increases during 3-D printing. Unlike VOCs, UFPs are not gases but rather microscopic pieces of material, usually ranging from 10nm to 10µm in size. The main concern is "their ability to penetrate deep into the lung" (Park et al., 2021). The lung vasculature provides a way to get inside the body and reach other organs. There they can cause diseases such as polymer fume fever (Schraufnagel, 2020). UFPs can also affect other various areas of the body including respiratory, cardiovascular, and nervous system. Additionally, under some conditions they hold the potential to mutate cells and cause cancer as "the finer the particle size, the greater the mutagenic potential" (Schraufnagel, 2020).



Risks for Children

All ages can be affected by the pollutants mentioned previously, but "Children are more vulnerable to the health effects of air pollution, and these effects may begin with in utero exposure and have lifelong consequences" (Schraufnagel, 2020). This is an alarming statement as one of the 3-D pen industry's target audiences is children. The truth behind this claim can be seen in the schools themselves, as most schools for younger children (who are considered as people ages 6-12 as defined by the CPSC staff) lack sufficient knowledge about health and safety procedures. If necessary safety precautions are not followed, the classrooms can have elevated concentrations of VOCs or UFPs during use of these products. These conditions contribute to the reality that children using 3-D printing pens, in the types of classrooms described formerly, are the ones who may be highly exposed to pollutants emitted by the filaments used during 3-D printing.

METHODOLOGY

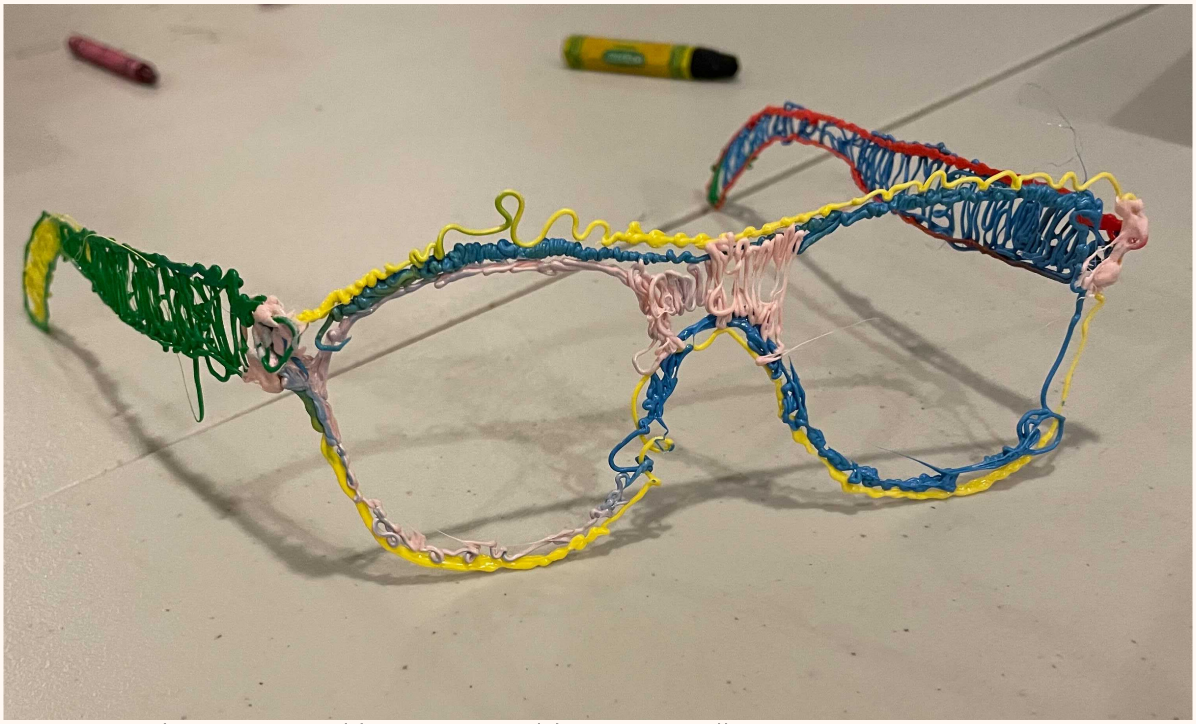


Figure 6: Glasses printed by a 7 year old using 3Dodler Start+ (Source: Prof. Hall-Phillips)

In order to accurately evaluate the health and safety hazards of using 3-D printing pens, data relevant to the outlined concerns was collected through quantitative and qualitative research. The data were retrieved based on the following research guidelines:

- Identify Who, What, Where, and How of 3-D printing pens?
- What are the currently recognized potential dangers associated with 3-D printing pens, and how can they be analyzed?
- What other aspects of 3-D printing pens are valuable to understand?

Identify Who, What, Where, and How of 3-D Printing Pens?

The following questions needed to be answered before exploring the hazards of 3-D printing pens:

1. Who is using 3-D printing pens?
2. What 3-D printing pen and filament is being used?
3. What setting are they being used in?
4. How are they being used?

The who and where were combined for this scenario since our primary goal was to look at presumably supervised use in schools. From there, specifics as to where they are being used, what filaments they are using, and how they are being used were considered. The necessary information was obtained using two methods: a semi-structured interview, which can be viewed in Appendix A, and a Qualtrics survey.

Administering the Interview and Survey

We found usable contacts by analyzing search results in Google, where we used the search phrase ‘3D pens in schools'. Some search results immediately directed us to schools using 3-D printing pens. However, most of the schools we contacted were found through articles reporting on prior or current 3-D printing pen use. The credibility of the articles were assessed through the following process: identifying the publisher of the article, identifying the name(s) of the individuals or schools associated with 3-D printing pens, and identifying contact information (via email). If the article passed our credibility assessment, then we contacted the teacher(s) (and administrators if applicable) of the school known to be using 3-D printing pens.

Semi-structured interviews allow the interviewer more control over the topic of conversation, while they allow the interviewee to expand on the topic. Semi-structured interviews were conducted with a preset list of questions. However, there was a possibility for additional questions to be asked if the interviewee provided a response that leads beyond the scope of the original question. The Qualtrics survey asked the same questions as the interview, but lends itself to people who do not have the time to be interviewed.

The responses collected from these two methods helped inform us about what brands of pens are most commonly used, the most commonly identified issues, what conditions the pens are being used in, and what safety hazards are evident and how they are being addressed, if at all. The responses from the interviews and surveys helped factor into the health and safety fact sheet.

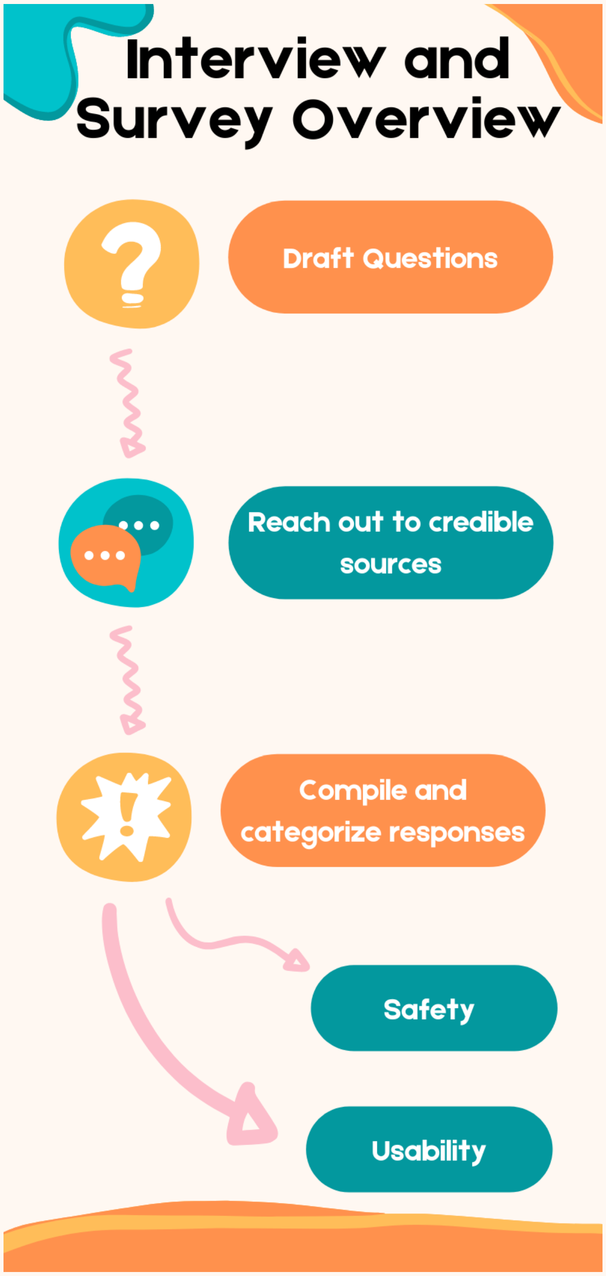


Figure 7: Interview and Survey Overview

Data Analysis

To analyze the responses, we followed a coding analysis process. The first step of forming analytical categories involved intensively reading the material, without comparing the content of different interviews, and taking notes on the topics. Our group went through the responses, discussed the main themes and topics of each, and noted each topic. Next, our group worked on creating a coding guide. We decided on 2 broad categories: Safety and Usability. The third step of analysis involved using the established coding guide to code the material. Our group read through each of the responses, and had a thorough discussion on which category it would fall into, if not both. Typically, the next step of analysis is to quantify the results of coding. However, due to the lack of responses, we did not formally quantify the results of our coding in a chart. Lastly, the final step of analysis included detailed case interpretations.

What are the Dangers Associated with 3-D Printing Pens?

Literature Review

The next method of gathering and evaluating data about 3-D printing pens was a literature review of various credible sources or journals. The references in the literature review were chosen by the WPI team, along with a health scientist from the CPSC. We reviewed how various tests were performed and the details of the procedures, chemicals tested, and other components of the testing or experimentation we deemed valuable. All of the crucial information was then put into a condensed chart to visually display our overall findings

Screening Process

Our literature review, conducted in November 2021, consisted of 2 initial steps:

1. Identification of potentially relevant data sources
2. Screening the selected data sources

We narrowed our research to two databases: Science Direct, Engineering Village. We also broadened the search using Google Scholar. Then, we gathered sources by following criteria we created, which included two parts. Each data source we selected must:

- Be related to 3-D printers or 3-D printer pens
- Be related to risk assessment, exposure assessment, or emissions

We found 25 relevant documents and screened those using our criteria. This resulted in n = 15 "seed articles" which were forward searched using Google Scholar. We added our first criteria phrase (3-D printer or 3-D printer pen) to focus on more relevant articles for forward search when a seed article had more than 10 citations. We compiled all the seed articles, their respective forward search results, and two Danish EPA studies (a forward search was not conducted for these articles) into a document which totaled 120 citations. After eliminating duplicates, the total number of unique references was 74, including the two Danish EPA reports. We then screened through these references using our screening criteria. After removing any citations that were not relevant, the total number of remaining citations was 38, including the two Danish EPA reports. We divided these 38 references equally amongst the team members and started the process of categorization and extraction. We also identified additional supplementary references containing valuable background information on 3-D printing pens and indoor air quality using this process.

Categorization and Extraction

The information from the 38 selected sources was collected by conducting a full categorization and extraction process. Categorization involves extracting summary level information from the articles, whereas extraction involves pulling out specific information from select articles. All 38 articles were categorized and only N = 16 articles were extracted. After extraction, we reviewed each other's work to ensure no important information was left out. This is called a Quality Control Step (QC Step).

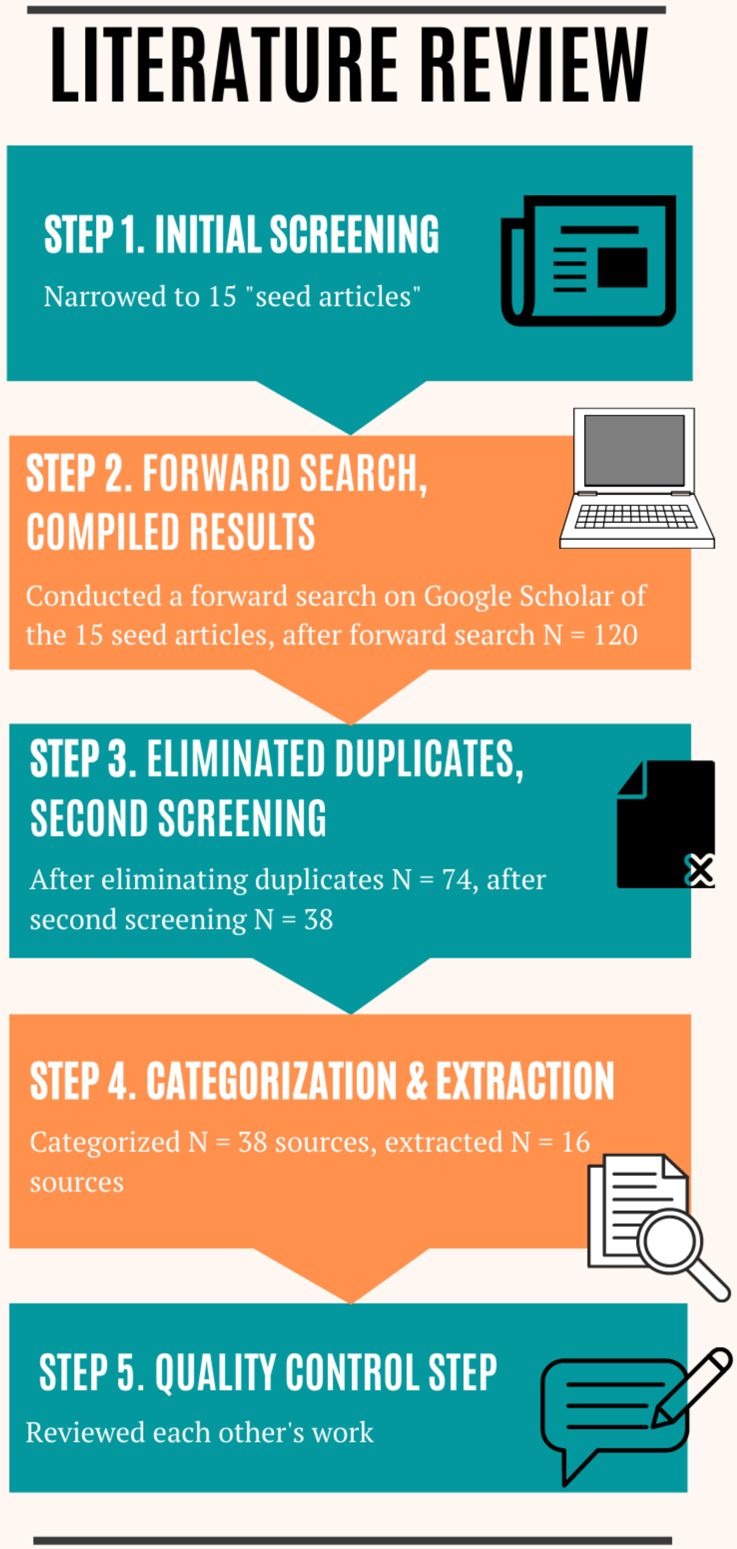


Figure 8: Literature Review Overview

What Other Aspects of 3-D Printing Pens are Valuable to Understand?

Our last method of gathering and evaluating data about 3-D printing pens was designing experiments based on characteristics we deemed important to test. With limited testing capabilities, these characteristics were more focused on usability and practicality rather than chemical components or emissions. Some characteristics that were analyzed include smoothness of extrusion, general weight of the pen, and ease of use. We also sought to identify any obvious potential hazards whether expected or unexpected.

MYNT3D PRO PEN

VERSUS

3DOODLER START+

COMPARING THE TWO 3-D PRINTING PENS

MYNT3D PRO PEN	3DOODLER START+
"Professional Printing 3D Pen"/ anyone who wants to "take your design projects to greater heights"	"for kids 6-13 years old "
Any 1.75mm filament and melts within pen temperature range	Eco-Plastic
Must be plugged in, continuous power source	Must be charged, runs on battery life
130 - 230 ℃	"Child-Safe: Designed with no external hot parts"/ 35 ℃

Figure 9: Comparing the two 3-D printing pens

Choosing the 3-D Printing Pen

There are several 3-D printing pen companies and within each of those companies, there are several models to choose from. However, not all pens are created equal and there are differences in pens that could make one pen safer than another. Two distinct 3-D printing pens have been reviewed across two brands: they are the Mynt3d Professional Printing 3D Pen with OLED Display and the 3Doodler Start+ 3D Pen. We chose these models and brands to evaluate because they appear most frequently on various 2021 top 3-D printing pen lists ("Best 3D Pens Reviewed & Tested In 2021 [Buying Guide] - GearHungry," n.d.);(The Best 3D Pen for 2021 | Reviews by Wirecutter, n.d.);(Best 3D Printing Pens for 2021 - Reviews of 3D Printing Pens, n.d.). Also we intentionally chose these two models because we wanted to explore the difference in usability and practicality for pens marketed toward different age groups while still being able to test the most different filaments. With the Mynt3d pen, we tested the Mynt3d brand PLA and ABS filaments, and with the 3Doodler pen, we tested 3Doodler brand Eco-Plastic filament.

Testing the 3-D Printing Pen

The team ran multiple user tests and took notes of the user's comments during and after use. The team and a few colleagues were the "users" during these tests. The feedback includes but is not limited to ease of use and what the user could see, smell, touch, and hear. Some users built a 2-D object while others a 3-D object. We did not restrict the user to what they wanted to create or how to create said object. The team ran additional tests on the Mynt3d pen to see if printing at a temperature higher or lower than the recommended filament print temperature affected the emissions.

Data Analysis

Like the interviews and survey, we followed the coding analysis process and coded the user comments into two categories, Safety and Usability.

Figure 10. 3Doodler Start+ (Source: Khalil Haboub)

Figure 11. Mynt3d Pro Pen (Source: Cameron Pelletier)

FINDINGS

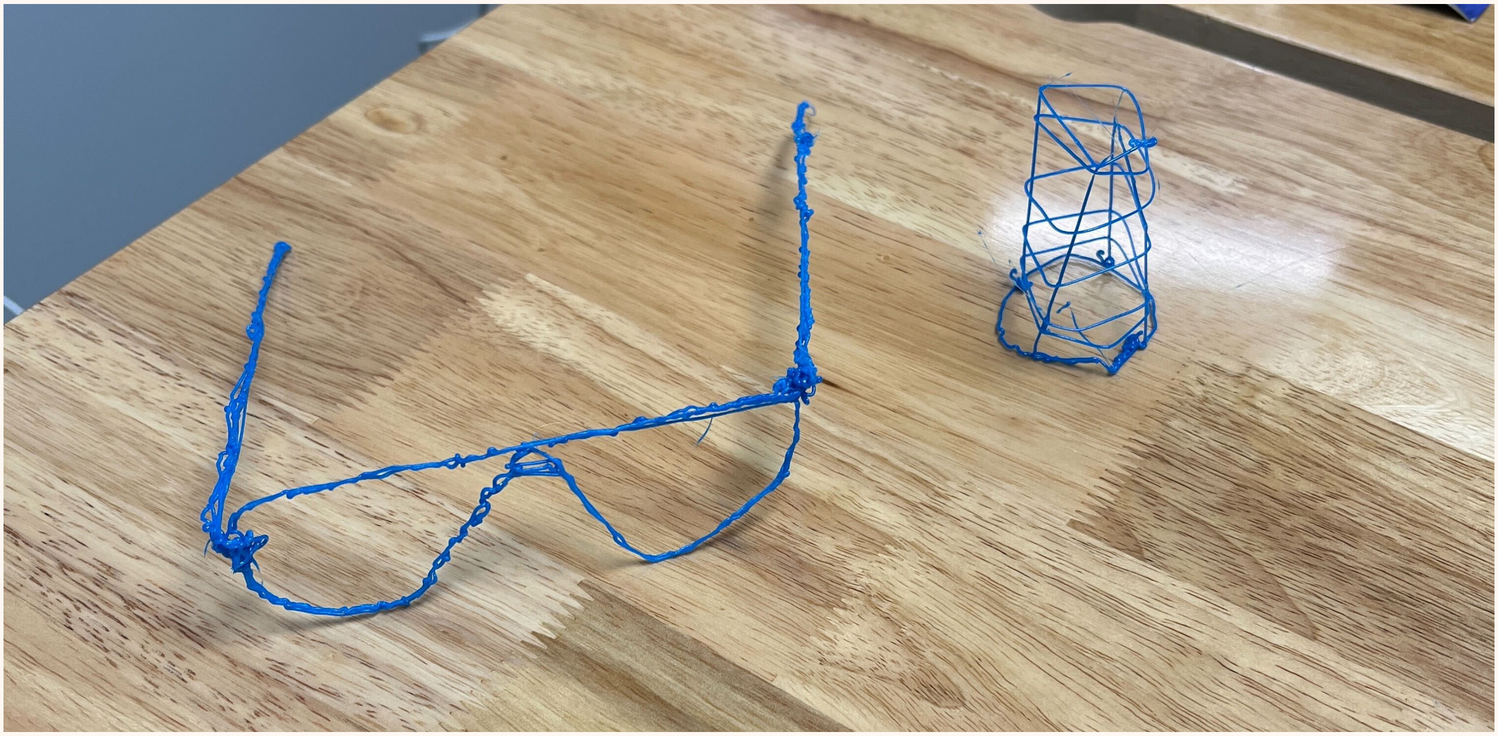


Figure 12: Glasses and 3-D object printed by our team using 3Doodler Start+ (Source: Cameron Pelletier)

The team was able to collect valuable information on the safety and usability of 3-D printing pen use. This was done applying the methods described previously, and from other complementary research. The collected data was used to create a health and safety fact sheet for the CPSC staff and 3-D printing pen users.

Safety

When discussing the pen's safety, participants indicated that the pen was safe as long as it was in capable hands. The majority of our participants noted the fumes and smells but they expressed little to no concern for them as a health hazard. They focused more on the potential for burn and constantly warned the students to not touch the tip. The following statements regarding safety were compiled because they contained a noteworthy concern or suggestion that will be addressed in the health and safety fact sheet.

From the Interviews and Survey

> "If you want to approach the pen tip and you want to grab at the filament if you're thinking I'm just going to do this and grab with my fingers and pull this, no bad idea, so use scissors you pinch it with the scissors and pull it away, use the metal to be ... this is your other pair of hands when you're using your 3D pen" - Three Year Pen User

From the Usability and Practicality Testing

- Mynt3d Pro Pen
  - The pen leaks filament in between and after use, which wastes product and increases the potential skin exposure and burn risk
  - Depending on what the user is creates, there is a potential for sharp edges
  - Fumes and noticeable smoke
- Specifically for Mynt3d Pro Pen with ABS
  - After 20-30 minutes of use, the burnt plastic smell is hard to not notice
- Specifically for Mynt3d Pro Pen with PLA
  - There is a maple syrup/sugary smell somewhat immediately
  - Noticeably stringy, which increases the potential skin exposure and burn risk
- 3Doodler Start+ with Eco-Plastic
  - These pens were very user safe, the tip is safe to touch, even after extruding
  - There was no leaking reported
  - The filament is malleable after extrusion, which increases the potential skin exposure and potential oral intake especially because this pen is marketed towards a younger audience who is more likely to put their hands in their mouths

Usability

When discussing the pen's usability, the majority of participants indicated that the pen to be easy to use with a slight learning curve when first using the pen. There were a portion of users that did experience technical issues such as jamming of the pen. Some were able to fix this issue while others had to buy new pens. Of the users who experienced jamming, one noted that it was from user error such as not removing the filament from the pen when it was finished being used. The following statements regarding usability were compiled because they contained a noteworthy concern or suggestion that will be addressed in the health and safety fact sheet.

From the Interviews and Survey

"it lasted a few months, a year maybe, until it got so clogged we weren't able to use it again ... the replacement we've had now it's at least three years old maybe four" -Three Year Pen User

"Some of the older Start filaments are very brittle. The newer filament is more flexible, although it is quite a bit stretchier and perhaps warranting careful/skillful handling. Kids tend to keep pulling and so the "filament hair" grows!" -Multiple Model User/Teacher

From the Usability and Practicality Testing

- Mynt3d Pro Pen regardless of the filament
    - Slight learning curve with understanding how the pen works and how it flows
    - Controlling the speed and figuring out what speed is best for the user is a part of the learning curve
    - A little challenging to build 3-dimensional objects depending on how the user decides to build said object
    - Must be near an outlet to use pen
- Mynt3d Pro Pen with ABS
- Mynt3d Pro Pen with PLA
    - Maple syrup smell
    - We tested prolonged use, starting with a new roll of filament (PLA) until it ran out, one roll of filament lasts 20 min 16 sec
- 3Doodler Start+ with Eco-Plastic
    - Very easy to use, no control over speed
    - Filament is inconsistent with hardening
    - We tested prolonged use, starting with a new strand of filament (Eco-Plastic) until it ran out, one strand of filament lasts about 3 min
    - No smoke, no fumes

Online Product Review Assessment

Our team also evaluated numerous Amazon reviews on the Mynt3D Pro Pen and 3Doodler Start+ to gauge the opinion of a wider audience of 3-D printing pen users. Reviews for both pens were generally centered around the usability aspects of the pens (Amazon.Com.
Spend Less. Smile More., n.d.).

The majority of the good reviews for the 3Doodler Start+ praised how easy the pen is to use for children, along with the avoidance of any burn hazards due to the low melting temp that the pen operates at (35 °C).

However, the bad reviews were much more in depth and critical of the pen than the good reviews. Pen jamming was a common complaint amongst many of the 1-3 star reviews, while other reviews commented on the pen suddenly not working, and the filament refills to be very expensive. For context on the filament refill complaints, 3Doodler requires users to purchase bundles of Eco Plastic filament through their website (75 strands for $11.99 or 200 strands for $29.99) (3D Printing Pen | The World's First and Best, n.d.). Some of the poor reviews also indicated that users were purchasing at least 1 more pen after the first one would break, and were also commenting on issues with the second or other additional pens.

"

Gotta say it works better than expected. It does have a learning curve, but once you figure out how to properly set speeds, temperature, and when to let go of the button it's fairly easy to use.
This was definitely the best pen for me being an advanced tech user. Offering full temp and speed control, and let's you use ANY filament that's 1.75mm. unlike other brands which force you to buy proprietary filament. Get this if you want a versatile 3D pen.

"

Figure 13. 5/5 Star Amazon Review of 3Doodler Start+ (Source: Amazon)

The majority of the good reviews for the Mynt3D Pro Pen concentrated on the pen's high quality, from the pen itself to the filaments used (ABS and PLA). A variety of comments were made across different reviews. Some noted the pen's relative quick heating time, others focused on certain aspects of the filaments such as loading in more filament to the pen and the pen's capability to use ABS and PLA filaments from other brands. However, most of the positive reviews we analyzed mentioned that there was a required learning curve in order to avoid any malfunctions.

Speaking of malfunctions, pen jamming and inconsistent extrusion were among many complaints across the poor reviews we looked at. Other complaints include the pen's motor not working, and even receiving used, defective models after purchase.

"

When it worked it was okay, the feed was thin so it was difficult to pull out. I did like that the tip itself was protected and was mostly cool so you it's difficult for little fingers to get burnt.

The device stopped feeding after using about 2-3 times, Even during the first few uses it took some pushing to get the included material to start to feed. After about the 4th use Pulled it out and could not get the material to feed, getting the material out was very difficult and I tried a few different sticks to no avail. I returned and purchased something different as it appears to be an issue with this product and I didn't want this to occur a second time and be out of the return / replacement window.

"

Figure 14. 2/5 Star Amazon Review of Mynt3D Pro Pen (Source: Amazon)

Discoveries on Prior 3-D Printing Research

Conducting the literature review revealed insightful information on prior 3-D printer and 3-D printer pen testing.

Categorization

First, the majority of the 38 sources we analyzed were categorized into at least one of the following two types of testing: Exposure Assessment, and Emissions Testing. Exposure assessment studies describe how a person is exposed and calculates a "dose" in mass per body weight per time. Emissions testing studies describe how 3-D printers, and 3-D printer pens, emit to chambers and/or the indoor air. Different types of chemicals and filaments were featured across all the sources we reviewed. Volatile organic compounds (VOCs), were the most common type of chemicals analyzed, with ABS and PLA being the two most common filament types analyzed.

Extraction

Once the categorization was completed, we began to extract certain information from our sources. The most significant information we extracted includes the following: chemical analyzed, sampling approach, and results (including a descriptor and units).

There were a considerable amount of chemicals analyzed across all the studies. The chemicals that kept reoccurring during the process of extracting comprise of the following: styrene, acetaldehyde, acetone, 1-butanol, caprolactam, formaldehyde, toluene, benzene, ethylbenzene, acrylonitrile, lactide, and lactic acid. These chemicals were sampled through various means, but there were some common practices amongst many of the studies. First, tests were performed in a sealed testing chamber in order to create an isolated environment and ensure repeatable and scalable VOC emission collection. Another frequent practice was the use of calibrated sampling pumps, which were used to collect the VOC samples from the 3-D printing tests. There were also similarities in the types of results analyzed in each of the studies. Most of the studies assessed certain information relating to the concentrations of specific VOCs within each sample. Particle concentrations, mass concentrations, and volume concentrations were the most prevailing types of concentration data analyzed across the majority of the studies.

Physical Characteristics

We were able to identify key physical characteristics relating to 3-D printing filaments. First, the temperature at which the filaments are being exposed to during extrusion affects the level of VOC emissions. More specifically, VOC emissions increase as the extrusion temperature increases. Another key characteristic we found is that using ABS is potentially more dangerous than using PLA for 3-D printing. This is because extruding ABS filament requires a higher operating temperature, thus making VOC emissions higher for ABS than PLA. ABS also emits styrene in larger quantities than all other VOC emissions. Direct exposure to styrene is known to cause immediate symptoms, including irritation of the skin and eyes (Styrene - Hazard Recognition | Occupational Safety and Health Administration, n.d.). Finally, we found that the color of the filament is associated with the VOC emissions. More notably, dark-colored filaments (including black, blue, and red) emit a higher concentration of VOCs than light-colored filaments (including white, yellow, and neon green).

Label Review

Warning labels are important because they help reduce the potential for injury or risk when using a consumer product. Even though they can be easily looked over or forgotten they still make a difference. The team wanted to review and compare the warning labels on the 3-D pens.

Of the two 3-D printing pens our team purchased, there are few safety warnings or hazard labels featured in the packaging for popular 3-D printing pens. Our team confirmed this by buying two popular 3-D printing pens, the 3Doodler Start+ and the Mynt3d Pro Pen, and conducting a label review for each pen.

We first detailed the 3Doodler Start+, which is marketed to 6 - 13 year old's, and we found to have only one choking hazard label on the front of the box. This is due to the possibility of printing small parts that could be ingested. Nowhere on the box nor in the instruction manual is there a burn warning, or a warning to not have the pen near any water. Due to the pen having electrical components, there is also the possibility of a malfunction that results in the pen not working, or even a small fire.

Figure 15. 3Doodler Start+ Box (Source: Khalil Haboub)

With the Mynt3d Pen Pro, there are no visible warnings on the box as it is marketed toward older consumers with more experience. In the user manual, they state "do not touch the tip or melted plastic." This is the only warning we were able to find in the Mynt3d Pen Pro, but because the pen must be plugged into the wall outlet, there should also be a label instructing users to not to use the pen near water.

Health and Safety Fact Sheet

When creating a health and safety fact sheet, we thought about what factors we could control to reduce exposure. We used the National Institute for Occupational Safety and Health's (NIOSH) hierarchy of controls to help inform us as to what methods would be most effective. This hierarchy "has been used as a means of determining how to implement feasible and effective control solutions" (*Hierarchy of Controls | NIOSH | CDC*, 2021).

We concluded the health hazard of 3-D printing pens was not severe enough to consider Elimination so instead we focused on Administrative Controls and Personal Protective Equipment (PPE). To create our fact sheet, we reviewed other health and safety facts sheets, of 3-D printers and of other products, so we could understand what elements should be included. Additionally, we incorporated the feedback from other aspects of the project. Our Health and Safety Fact Sheet can be viewed in Appendix B.

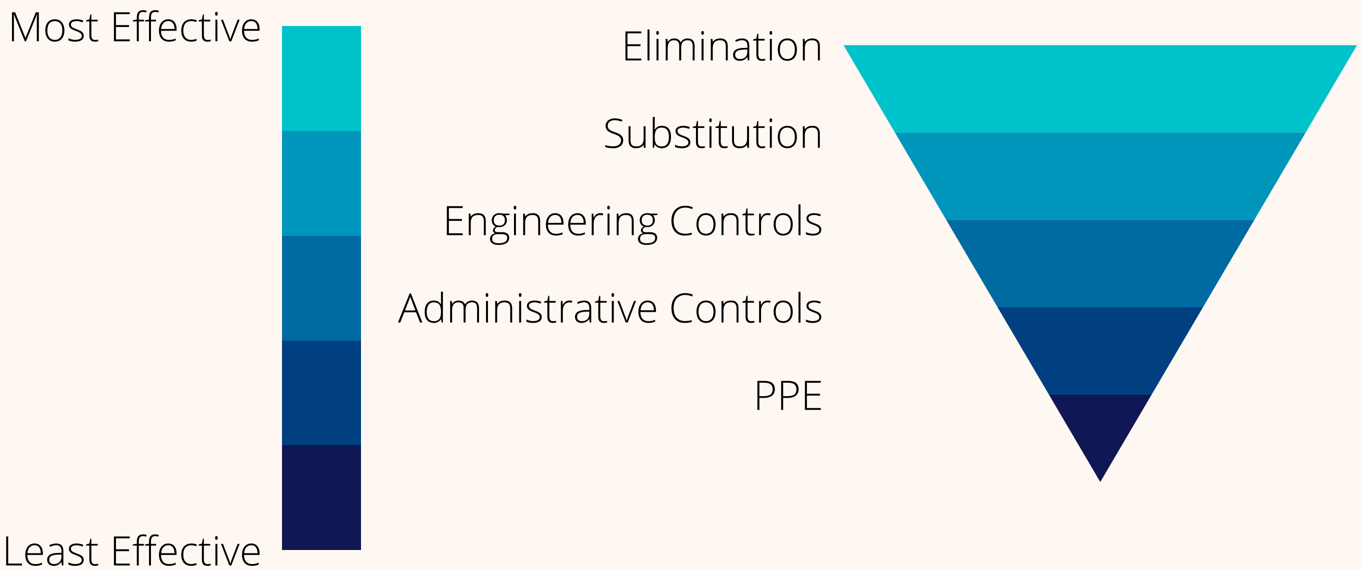


Figure 16. Hierarchy of Controls

NOTE:
Elimination - Physically remove the hazard
Substitution - Replace the hazard
Engineering Controls - Isolate people from the hazard
Administrative Controls - Change the way people work
PPE - Protect the worker with Personal Protective Equipment

CONCLUSIONS

3-D printing pens are a product with no set rules, regulations, or preliminary safety training. The team has identified more hazards than what are currently expressed to consumers by manufacturers' labels. The concentrations and distribution of VOCs and ultrafine particles in a room are not fully known. Furthermore, the exact exposure to

Figure 17. Main Takeaways

VOCs and ultrafine particles that a regular user would experience is not known. The distribution is especially important because the 3-D printing pens require the user to be in close proximity to the pen's emissions. Additionally, depending on the pen and the filament used, the user's exposure could vary greatly. We believe there has not been enough research done to determine the relative severity of the hazards mentioned, plus others that were not mentioned. Brands must alert their consumers of safety concerns, especially for products designed for children. Without proper knowledge, companies can not effectively or accurately warn consumers. In short, there is a lack of concrete evidence on the hazards linked to 3-D printing pens which could lead to preventable injuries. Thus, we created provisions specific to 3-D printing pens in the form of our Health and Safety Fact Sheet. This will account for possible gaps that general regulations do not account for such as emission hazards.

Study Limitations

The process of finding contacts from schools known to be using 3-D printing pens was much harder than anticipated. Articles about a 3-D printing pen being used in the classroom were not one of the first search results when we searched ‘3D pens in schools'. We had to look a few pages into the search to find relevant articles because advertisements for the pens cluttered the first few pages. Moreover, we assumed that because the pens were marketed to teachers and it is a fairly new technology for the classroom, there would be more news articles detailing this new addition to the classroom. Our assumption was wrong, which resulted in a small pool of people to contact and an even smaller pool of people who responded to our inquiry emails. Nonetheless from the responses we received, their answers were valuable in telling us how the pens were used in an educational setting.

Conducting the literature review during the IQP process proved to create a challenging time conflict for the team. The work required to complete the 3-D printing pen workbook could have been done over the course of ID 2050. However, the workbook was done during the peak of the IQP process, with an estimated timeline for completion being 11/3-11/18. These two weeks could have been used to possibly set up formal emissions tests at the CPSC facility in Rockville, MD. Even if the emissions testing were able to be done, the quantitative data from the emissions sampling would not be ready by the end of our time in DC.

There was also an issue with gathering enough prior studies on 3-D printing pens to analyze. Out of all the 38 sources we categorized and extracted, only 3 of the sources focused on studies with 3-D printing pens. Thus, most of our findings on prior 3-D printing studies were based on tests with stationary 3-D printers.

Future Research

Testing products requires both time and money to be able to properly test for hazards. Our team was limited in both aspects only having seven weeks and limited to products we purchased with our personal funds. We do believe that more extensive future testing should be done on pens with regards to the following categories: chemical hazards, burn hazards, ingestion hazards, and electrical hazards. We worked with the CPSC staff and an industrial hygienist to create an emissions sampling plan, however there were time and budget constraints that prevented completing the sampling. For the other three hazards, our team came up with some elementary testing ideas that could be used to evaluate each of those hazards. Since these are basic ideas, they could be expanded upon and added to better fit proper testing of 3-D printing pens.

Emission Hazards

The exposure to VOCs and Ultrafine particles by the user of the 3-D printing pen was one hazard explored. VOCs and ultrafine particles do not have uniform concentrations within the room, making it difficult to know the exact concentration in the user's personal breathing zone. However, by analyzing past emissions testing in the literature review, we were able to understand how to effectively collect and analyze samples to determine the air concentration.

Sampling Plan

Our team considered many variables of the pens and the filaments to test. The CPSC staff provided us with a "big room" and a "small room" to conduct the sampling in. We also previously purchased two 3-D printing pens, the 3Doodler Start+ and the Mynt3d Pro Pen. The 3Doodler pen can only take 3Doodler's Eco-Plastic filament and there is no variation in speed or temperature. On the other hand, as indicated by the instructions, the Mynt3d pen can take "any 1.75mm filament and melts within temperature range" and the user can change the speed and temperature of extrusion. After much deliberation and factoring in the cost and time, we decided on the following sampling plan.

Procedure

1. Use the pen for an hour (or until the battery dies for the 3Doodler pen), continuous at set speed and measure emissions
    a. Weigh the spools and strands before extrusion, weigh the leftover filament, and weigh the extruded material
2. Wipe down surfaces prior to and in between testing, wait 30 minutes in between testing
    a. Big Room
        i. Mynt3d Pen, Mynt3d ABS black, medium speed, high temp 230 ℃
        ii. Mynt3d Pen, Mynt3d ABS black, medium speed, recommended temp 210 ℃
        iii. Mynt3d Pen, Mynt3d PLA black, medium speed, high temp 185 ℃
        iv. Mynt3d Pen, Mynt3d PLA black, medium speed, recommended temp 175 ℃
    b. Small Room
        i. Mynt3d Pen, Mynt3d ABS black, medium speed, high temp 230 ℃
        ii. Mynt3d Pen, Mynt3d ABS black, medium speed, recommended temp 210 ℃
        iii. Mynt3d Pen, Mynt3d PLA black, medium speed, high temp 185 ℃
        iv. Mynt3d Pen, Mynt3d PLA black, medium speed, recommended temp 175 ℃
        v. 3Doodler, 3Doodler Eco-Plastic black

Factors Considered

- We chose the black color filament because we learned from the literature review that darker filaments have a higher concentration of certain chemicals. We also chose to stay consistent between the filament color.

- We did not vary the speed because at the highest speed, it is too uncontrollable and at the lowest speed, it barely extrudes. We marked the pen somewhere in the middle because we thought it was a good extrusion speed and to stay consistent in case we accidentally adjusted the slider while testing. Also, testing various speeds would double or triple the amount of sampling.
- We decided to vary the temperature between recommended and higher than recommended (while still staying within the temperature range) because we learned from the literature review that higher than recommended temperatures had the worst emissions, lower than recommended temperatures had the second worst emissions, and recommended temperatures had the least amount of emissions.
- We did not want the test subject to make an object because it is hard to be consistent between trials with the amount of filament extruded and the time it takes to make an object.

Analysis of Samples

There are different ways to analyze samples depending on what chemicals are being analyzed. The National Institute for Occupational Safety and Health (NIOSH) has many set methods for analyzing various VOCs. One such method is the NIOSH 1501, which detects chemicals significant to 3-D printing. These chemicals include styrene, toluene, and benzene. Our analysis includes NIOSH 1501 and NIOSH 7303, which detects metals in the air. To analyze the particles' size and count in the air, we planned to use TSI P-TRAK 8525 Ultrafine Particle Counter and TSI AeroTrak 9306 Optical Particle Counter. To collect the particles samples in the personal area, we planned to use an Ultrafine/Nano Personal Sampler. In addition to these methods we also wanted to collect data on dermal exposure from using the pen which would be gathered using dermal wipes of hands before and after use and processed through a wipe metal scan. Our Sample Schedule and Analysis can be viewed in Appendix C.

Alternative Emission Research

The team recognized that it takes extra time and funding in order to collect actual emission samples. So an alternative to gather data about emissions is to do exposure modeling. This is a less expensive way to collect data and shouldn't take as much time since it can be done using modeling software. There are multiple variations of modeling software, some that are simple and require few inputs and give a basic result. Others are more complex and require detailed inputs and provide a broader more accurate result.

Burn Hazards

Using a 3-D printing pen also involves the necessity of melting down material so it can be extruded. In order to do so, a high enough temperature has to be reached in order to reach the melting point of the material to be extruded. From the team's research, pens can range from 35 to 240 °C in order to achieve the melting points of various materials (MYNT3D, n.d.); (Nintenfoxy1983, 2020). To put this in perspective, a hot glue gun typically ranges between 80 to 200 °C. To examine the risks of using these high temperatures two main questions could be asked: What can cause burns? How do pens cause such burns?

Looking at what can cause burns would be explored first. Hot points exposed on the pen and temperature of the filament once it gets extruded are the most obvious points of risk. Observing how a person uses the pen could show various ways the user could touch the pen or the filament that would result in them getting burned.

Data can also be collected on the following information regarding individual pens:

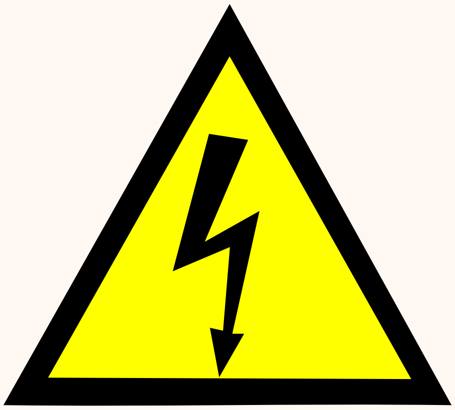
- What maximum temperature can the pens reach?
- Where the specific hot points on each pen are located?
- Is there any additional burn safety protection that comes with the pen, such as silicon finger protectors?

Ingestion Hazards

3-D printing pens use a variety of materials but most utilize some form of plastic filaments. Due to this use of majority plastic filaments and the primary user of pens being children, ingestion hazards also need to be addressed. The various filaments could be examined to see if they are made up of any chemicals, that if eaten or subject to oral exposure in any way, are toxic or leave behind toxic chemical residue on surfaces touched. This includes eating the filament before or after it has been melted as well as putting the users' hand in their mouth after they use a pen. Additionally, looking at the various ways the ingestion of materials could harm humans, such as internal lacerations from sharp pieces of plastic or chemicals being absorbed into the body could be explored.

Electrical Hazards

3-D printing pens are electrical devices, and with every electrical device comes the potential of electrical hazards. To explore these hazards tests should be performed on the pens to see how its electric components react under certain scenarios. Some possible tests include exposing the pen to water to see if short circuiting happens. A destructive drop and crushing tests could be employed to see how electric components react under strenuous conditions. Additionally, not all pens are powered the same way, some use disposable batteries while others use a cord and require being plugged into a wall outlet to charge reusable batteries. The different sources used could present their own hazards such as frayed cords or easily accessible batteries that could cause injury.



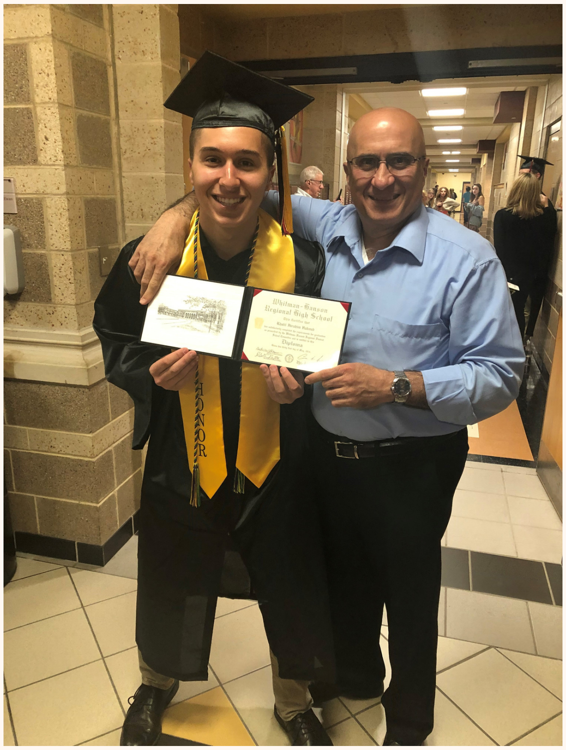
OUR EXPERIENCES

Carter Bach

My time in DC has taught me how to handle multiple differing inputs and opinions on one project. As a group, we had to deal with many changes and unexpected outcomes. I believe we handled these as best as we could and I commend everyone on keeping our composure and rolling with the changes. The 7 weeks I was working with the CPSC staff allowed me to see some of the inner workings of the U.S. Government which I found very interesting. Overall, My experience on this project will help me greatly in the future, as it prepared me to deal with the unexpected.

Khalil Haboub

Being able to work in DC was an eye-opening experience for me. Although it was not what I imagined what it would be, I was still able to appreciate process. While work was tedious at times, I was able to get a glimpse as to what the real work world looks like. I learned to expect the unexpected, adapt to new circumstances, and remain positive when faced with challenges.

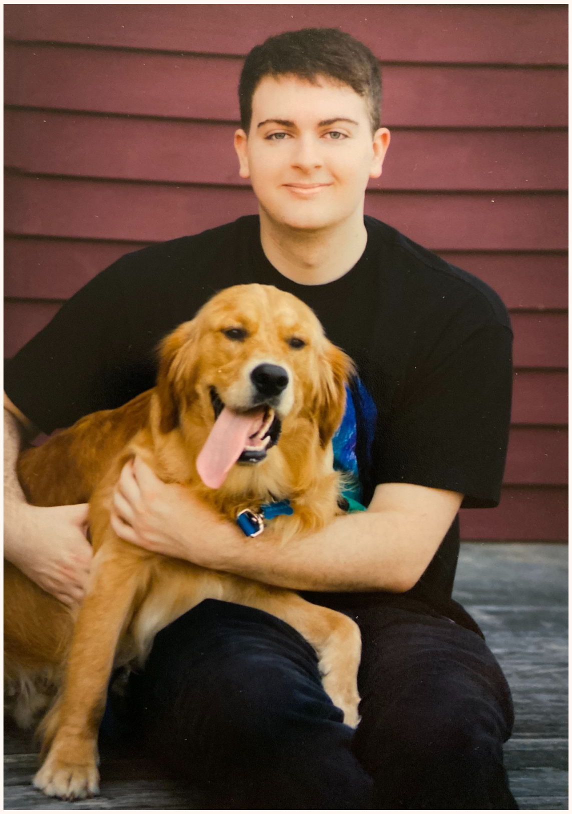


Grace Magnotta

I have thoroughly enjoyed my time in DC. It was fun living in the city and trying all the different cuisines. I also had a great time working with the CPSC staff. Although the project looked a little different then what I had originally expected, I still think our team contributed valuable initial research into 3-D printing pens. Additionally, getting to see the testing labs and talking with the engineers was beneficial for me because it helped me connect the concepts and lessons from class to real world situations.

Cameron Pelletier

DC was a great time between the museums, monuments, and food. It was interesting to work with the CPSC staff and see what goes on behind the scenes on product safety. I have been using 3-D printers over 6 years and had not once thought about the issue they could potentially hold. Despite this project being directed towards 3-D printing pens a lot of potential safety hazards of 3-D printers were brought to my attention due to the similarities between them. I am thankful that CPSC staff gave this opportunity to work with them.



REFERENCES

3D Printing Pen | The World's First and Best. (n.d.). 3Doodler. Retrieved September 24, 2021, from https://the3doodler.com/

3dsourced. (2020, June 24). The Complete PETG Filament 3D Printing Guide. 3DSourced. https://www.3dsourced.com/3d-printer-materials/petg-filament/

ABS. (n.d.). TMFilament. Retrieved October 29, 2021, from https://tmfilament.com/products/abs/

Amazon.com. Spend less. Smile more. (n.d.). Retrieved November 3, 2021, from https://www.amazon.com/

Bernatikova, S., Dudacek, A., Prichystalova, R., Klecka, V., & Kocurkova, L. (2021). Characterization of ultrafine particles and VOCs emitted from a 3D printer. *International journal of environmental research and public health*, *18*(3), 929. https://doi.org/10.3390/ijerph18030929

Best 3D Pens Reviewed & Tested In 2021 [Buying Guide]—Gear Hungry. (n.d.). GearHungry. Retrieved October 8, 2021, from https://www.gearhungry.com/best-3d-pen/

Best 3D Printing Pens for 2021—Reviews of 3D Printing Pens. (n.d.). Retrieved November 4, 2021, from https://best.offers.com/best-3d-printing-pens?path=zbe-36712-cob-100j1a&creative=78202913706794&device=c&keyword=78202850471728&source=s&msclkid=bcbdfa598db11fa0099d9bda7a13c852&utm_campaign=283220164&utm_content=1251244339995544&utm_medium=cpc&utm_source=bing&utm_term=top+10+3d+pens

Byrley, P., Boyes, W. K., Rogers, K., & Jarabek, A. M. (2021). 3D printer particle emissions: Translation to internal dose in adults and children. *Journal of Aerosol Science*, *154*, 105765. https://doi.org/10.1016/j.jaerosci.2021.105765

Carcano, A. M. (2021). *Effects of 3D printing nano-aerosol emissions and microplastics on A549 Epithelial Lung Cells* (Doctoral dissertation). https://hdl.handle.net/2346/87931

Cardoso, R. M., Rocha, D. P., Rocha, R. G., Stefano, J. S., Silva, R. A. B., Richter, E. M., & Muñoz, R. A. A. (2020). 3D-printing pen versus desktop 3D-printers: Fabrication of carbon black/polylactic acid electrodes for single-drop detection of 2,4,6-trinitrotoluene. *Analytica Chimica Acta*, *1132*, 10–19. https://doi.org/10.1016/j.aca.2020.07.034

Chan, F. L., Hon, C. Y., Tarlo, S. M., Rajaram, N., & House, R. (2020). Emissions and health risks from the use of 3D printers in an occupational setting. *Journal of Toxicology and Environmental Health*, *Part A*, *83*(7), 279-287. https://doi.org/10.1080/15287394.2020.1751758

Chen, R., Yin, H., Cole, I. S., Shen, S., Zhou, X., Wang, Y., & Tang, S. (2020). Exposure, assessment and health hazards of particulate matter in metal additive manufacturing: A review. *Chemosphere*, *259*, 127452. https://doi.org/10.1016/j.chemosphere.2020.127452

CPSC. (2016, January 8). Indoor Air Pollution: Introduction for Health Professionals. CPSC.Gov. https://www.cpsc.gov/safety-education/safety-guides/home/indoor-air-pollution-introduction-health-professionals

CPSC.gov. (n.d.). U.S. Consumer Product Safety Commission. Retrieved December 5, 2021, from https://www.cpsc.gov/

Davis, A. Y., Zhang, Q., Wong, J. P. S., Weber, R. J., & Black, M. S. (2019). Characterization of volatile organic compound emissions from consumer level material extrusion 3D printers. *Building and Environment*, *160*, 106209. https://doi.org/10.1016/j.buildenv.2019.106209

de Oliveira, F. M., de Melo, E. I., & da Silva, R. A. (2020). 3D Pen: A low-cost and portable tool for manufacture of 3D-printed sensors. *Sensors and Actuators B: Chemical*, *321*, 128528. https://doi.org/10.1016/j.snb.2020.128528

Ding, S., Wan, M. P., & Ng, B. F. (2020). Dynamic analysis of particle emissions from FDM 3D printers through a comparative study of chamber and flow tunnel measurements. *Environmental Science & Technology*, *54*(22), 14568-14577. https://doi.org/10.1021/acs.est.0c05309

Dobrzyńska, E., Kondej, D., Kowalska, J., & Szewczyńska, M. (2021). State of the art in additive manufacturing and its possible chemical and particle hazards. *Indoor Air*. https://doi.org/10.1111/ina.12853

Farcas, M. T., McKinney, W., Qi, C., Mandler, K. W., Battelli, L., Friend, S. A., ... & Qian, Y. (2020). Pulmonary and systemic toxicity in rats following inhalation exposure of 3-D printer emissions from acrylonitrile butadiene styrene (ABS) filament. *Inhalation toxicology*, *32*(11-12), 403-418. https://doi.org/10.1080/08958378.2020.1834034

Fusion 3 Design. (n.d.). Retrieved September 14, 2021, from https://secure.livechatinc.com/

Hierarchy of Controls | NIOSH | CDC. (2021, October 27). https://www.cdc.gov/niosh/topics/hierarchy/default.html

Indoor Air Quality Scientific Findings Resource Bank Berkeley Lab. (n.d.). Ventilation rates and health in homes. https://iaqscience.lbl.gov/ventilation-rates-and-health-homes

Jacobsen, E. (Ed.). (2017). Risk Assessment of 3D printers and 3D Printed products. *Environmental Protection Agency*.

Jones, A. P. (1999). Indoor air quality and health. *Atmospheric Environment*, *33*(28), 4535-4564. https://doi.org/10.1016/S1352-2310(99)00272-1

Junior 3D Pen for Kids Bundle—MYNT3D. (n.d.). Retrieved November 2, 2021, from https://www.mynt3d.com/products/junior-3d-pen-for-kids-bundle

Karayannis, P., Petrakli, F., Gkika, A., & Koumoulos, E. P. (2019). 3D-printed lab-on-a-chip diagnostic systems-developing a safe-by-design manufacturing approach. *Micromachines*, 10(12), 825. https://doi.org/10.3390/mi10120825

KUUSISTO-LUKKARI, K. (2021, June 25). What are the best 3D pens on the market? *3Dnatives*. https://www.3dnatives.com/en/top-15-3d-printing-pen160820184/

LulzBot Mini Desktop 3D Printer: Amazon.com: Industrial & Scientific. (n.d.). Retrieved September 14, 2021, from https://www.amazon.com/LulzBot-Mini-Desktop-3D-Printer/dp/B00S54E1AI

MacCuspie, R. I., Hill, W. C., Hall, D. R., Korchevskiy, A., Strode, C. D., Kennedy, A. J., ... & Hull, M. S. (2021). Prevention through design: insights from computational fluid dynamics modeling to predict exposure to ultrafine particles from 3D printing. *Journal of Toxicology and Environmental Health, Part A*, *84*(11), 458-474. https://doi.org/10.1080/15287394.2021.1886210

Mak, S. L., Tang, W. F., Li, C. H., Wu, M. Y., & Lai, C. W. (2020, November). A Study on the ways to solve Hazardous Chemical Emission from 3D Printing Process. In *2020 IEEE International Symposium on Product Compliance Engineering-Asia (ISPCE-CN)* (pp. 1-5). IEEE. https://doi.org/10.1109/ISPCE-CN51288.2020.9321822

Manoj, A., Bhuyan, M., Banik, S. R., & Sankar, M. R. (2021). Review on particle emissions during fused deposition modeling of acrylonitrile butadiene styrene and polylactic acid polymers. *Materials Today: Proceedings*, *44*, 1375-1383. https://doi.org/10.1016/j.matpr.2020.11.521

Min, K., Li, Y., Wang, D., Chen, B., Ma, M., Hu, L., ... & Jiang, G. (2021). 3D Printing-Induced Fine Particle and Volatile Organic Compound Emission: An Emerging Health Risk. *Environmental Science & Technology Letters*, *8*(8), 616-625. https://doi.org/10.1021/acs.estlett.1c00311

MYNT3D. (n.d.). The Best 3D Pens For Artists and Creators. *MYNT3D*. Retrieved November 3, 2021, from https://www.mynt3d.com/

Ng, O.-L., & Ferrara, F. (2020). Towards a Materialist Vision of 'Learning as Making': The Case of 3D Printing Pens in School Mathematics. *International Journal of Science and Mathematics Education*, *18*(5), 925-944. https://doi.org/10.1007/s10763-019-10000-9

Nintenfoxy1983. (2020, February 15). What temperature does the 3doodler Start filament melt at? [Reddit Post]. R/3Doodler. www.reddit.com/r/3Doodler/comments/f4b1rb/what_temperature_does_the_3doodler_start_filament/

O'Neal, B. (2016, February 9). *Pre-Order 3Doodler Start Now: 3D Printing Pen Designed for Younger Kids, Safe & Simple to Operate*. 3DPrint.Com | The Voice of 3D Printing / Additive Manufacturing. https://3dprint.com/118842/3doodler-start-3d-printing-pen/

Park, J., Kwon, O., Yoon, C., & Park, M. (2021). Estimates of particulate matter inhalation doses during three-dimensional printing. *Indoor Air*, *31*(2), 392-404. https://doi.org/10.1111/ina.12736

Park, J., Kwon, O. H., Yoon, C., & Park, M. (2021). Estimates of particulate matter inhalation doses during three-dimensional printing: How many particles can penetrate into our body?. *Indoor air*, *31*(2), 392-404. https://doi.org/10.1111/ina.12736

PCL. (n.d.). TMFilament. Retrieved October 29, 2021, from https://tmfilament.com/products/pcl/

PETG. (n.d.). TMFilament. Retrieved October 29, 2021, from https://tmfilament.com/products/petg/

PLA. (n.d.). TMFilament. Retrieved October 29, 2021, from https://tmfilament.com/products/pla/

Potter, P. M., Al-Abed, S. R., Hasan, F., & Lomnicki, S. M. (2021). Influence of polymer additives on gas-phase emissions from 3D printer filaments. *Chemosphere*, *279*, 130543. https://doi.org/10.1016/j.chemosphere.2021.130543

Runström Eden, G., Tinnerberg, H., Rosell, L., Möller, R., Almstrand, A. C., & Bredberg, A. (2021). Exploring Methods for Surveillance of Occupational Exposure from Additive Manufacturing in Four Different Industrial Facilities. *Annals of Work Exposures and Health*. https://doi.org/10.1093/annweh/wxab070

Schraufnagel, D. E. (2020). The health effects of ultrafine particles. *Experimental & Molecular Medicine*, *52*(3), 311-317. https://doi.org/10.1038/s12276-020-0403-3

Secondo, L. E., Adawi, H. I., Cuddehe, J., Hopson, K., Schumacher, A., Mendoza, L., ... & Lewinski, N. A. (2020). Comparative analysis of ventilation efficiency on ultrafine particle removal in university MakerSpaces. *Atmospheric Environment*, *224*, 117321. https://doi.org/10.1016/j.atmosenv.2020.117321

Shahrubudin, N., Lee, T. C., & Ramlan, R. (2019). An Overview on 3D Printing Technology: Technological, Materials, and Applications. *Procedia Manufacturing*, *35*, 1286-1296. https://doi.org/10.1016/j.promfg.2019.06.089

Shim, B. S., Shin, Y. S., Park, S. W., & Hou, J. U. (2021, October). SI3DP: Source Identification Challenges and Benchmark for Consumer-Level 3D Printer Forensics. In *Proceedings of the 29th ACM International Conference on Multimedia* (pp. 1721-1729). https://doi.org/10.1145/3474085.3475316

Sigloch, H., Bierkandt, F. S., Singh, A. V., Gadicherla, A. K., Laux, P., & Luch, A. (2020). 3D printing-evaluating particle emissions of a 3D printing pen. *JoVE (Journal of Visualized Experiments)*, (164), e61829. https://doi.org/10.3791/61829

Sin, L. T., & Tueen, B. S. (2019). 1—Overview of Biodegradable Polymers and Poly(Lactic Acid). In L. T. Sin & B. S. Tueen (Eds.), *Polylactic Acid (Second Edition)* (pp. 1-52). William Andrew Publishing. https://doi.org/10.1016/B978-0-12-814472-5.00001-7

Singh, A. V., Maharjan, R. S., Jungnickel, H., Romanowski, H., Hachenberger, Y. U., Reichardt, P., ... & Luch, A. (2021). Evaluating Particle Emissions and Toxicity of 3D Pen Printed Filaments with Metal Nanoparticles As Additives: In Vitro and in Silico Discriminant Function Analysis. *ACS Sustainable Chemistry & Engineering*, *9*(35), 11724-11737. https://doi.org/10.1021/acssuschemeng.1c02589

Stefaniak, A. B., Bowers, L. N., Cottrell, G., Erdem, E., Knepp, A. K., Martin, S., ... & Sirinterlikci, A. (2021). Use of 3-Dimensional Printers in Educational Settings: The Need for Awareness of the Effects of Printer Temperature and Filament Type on Contaminant Releases. *ACS Chemical Health & Safety*. https://doi.org/10.1021/acs.chas.1c00041

Stefaniak, A. B., Bowers, L. N., Martin Jr, S. B., Hammond, D. R., Ham, J. E., Wells, J. R., ... & Virji, M. A. (2021). Large-Format Additive Manufacturing and Machining Using High-Melt-Temperature Polymers. Part I: Real-Time Particulate and Gas-Phase Emissions. *ACS Chemical Health & Safety*, *28*. https://doi.org/10.1021/acs.chas.0c00128

Stefaniak, A. B., Bowers, L. N., Martin Jr, S. B., Hammond, D. R., Ham, J. E., Wells, J. R., ... & Virji, M. A. (2021). Large-Format Additive Manufacturing and Machining Using High-Melt-Temperature Polymers. Part II: Characterization of Particles and Gases. *ACS Chemical Health & Safety*, *28*. https://doi.org/10.1021/acs.chas.0c00129

Stefaniak, A. B., Du Preez, S., & Du Plessis, J. L. (2021). Additive Manufacturing for Occupational Hygiene: A Comprehensive Review of Processes, Emissions, & Exposures. *Journal of Toxicology and Environmental Health*, *Part B*, 1-50. https://doi.org/10.1080/10937404.2021.1936319

Styrene—Hazard Recognition | Occupational Safety and Health Administration. (n.d.). Retrieved December 5, 2021, from https://www.osha.gov/styrene/hazards

The Best 3D Pen for 2021 | Reviews by Wirecutter. (n.d.). Retrieved October 8, 2021, from https://www.nytimes.com/wirecutter/reviews/best-3d-pen/?AMNews

Tordrup, S. (Ed.). (2018). Survey and Risk Assessment of 3D Pens. Environmental Protection Agency.

US EPA, O. (2014, August 18). Volatile Organic Compounds' Impact on Indoor Air Quality [Overviews and Factsheets]. https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality

Uses for 3D printing 2015-2020. (n.d.). Statista. Retrieved September 24, 2021, from https://www.statista.com/statistics/560271/worldwide-survey-3d-printing-uses/

Vinyas, M., Athul, S. J., Harursampath, D., & Thoi, T. N. (2019). Experimental evaluation of the mechanical and thermal properties of 3D printed PLA and its composites. *Materials Research Express*, *6*(11), 115301. https://doi.org/10.1088/2053-1591/ab43ab

Wojtyła, S., Klama, P., Śpiewak, K., & Baran, T. (2020). 3D printer as a potential source of indoor air pollution. *International Journal of Environmental Science and Technology*, *17*(1), 207-218. https://doi.org/10.1007/s13762-019-02444-x

Wojnowski, W., Kalinowska, K., Gębicki, J., & Zabiegała, B. (2020). Monitoring the BTEX Volatiles during 3D Printing with Acrylonitrile Butadiene Styrene (ABS) Using Electronic Nose and Proton Transfer Reaction Mass Spectrometry. *Sensors*, *20*(19), 5531. https://doi.org/10.3390/s20195531

Wojnowski, W., Kalinowska, K., Majchrzak, T., & Zabiegała, B. (2022). Real-time monitoring of the emission of volatile organic compounds from polylactide 3D printing filaments. *Science of the Total Environment*, *805*, 150181. https://doi.org/10.1016/j.scitotenv.2021.150181

Yi, J., Duling, M. G., Bowers, L. N., Knepp, A. K., LeBouf, R. F., Nurkiewicz, T. R., ... & Stefaniak, A. B. (2019). Particle and organic vapor emissions from children's 3-D pen and 3-D printer toys. *Inhalation toxicology*, *31*(13-14), 432-445. https://doi.org/10.1080/08958378.2019.1705441

Youn, J. S., Seo, J. W., Han, S., & Jeon, K. J. (2019). Characteristics of nanoparticle formation and hazardous air pollutants emitted by 3D printer operations: From emission to inhalation. *RSC advances*, *9*(34), 19606-19612. https://doi.org/10.1039/C9RA03248G

Zhang, Q., Pardo, M., Rudich, Y., Kaplan-Ashiri, I., Wong, J. P., Davis, A. Y., ... & Weber, R. J. (2019). Chemical composition and toxicity of particles emitted from a consumer-level 3D printer using various materials. *Environmental science & technology*, *53*(20), 12054-12061. https://doi.org/10.1021/acs.est.9b04168

Zhu, Q., Yao, Q., Liu, J., Sun, J., & Wang, Q. (2020). Emissions from the fused filament fabrication 3D printing with lignocellulose/polylactic acid filament. *BioResources*, *15*(4), 7560. https://doi.org/10.15376/biores.15.4.7560-7572

Zontek, T. L., Hollenbeck, S., Jankovic, J., & Ogle, B. R. (2019). Modeling particle emissions from three-dimensional printing with acrylonitrile-butadiene-styrene polymer filament. *Environmental science & technology*, *53*(16), 9656-9663. https://doi.org/10.1021/acs.est.9b02818

APPENDIX A: INTERVIEW STRUCTURE

Do you consent to us recording this interview just in case we miss anything and need to go back. After we are done, we will delete the recording.

Hello (insert name),
Our names are [Carter Bach, Khalil Haboub, Grace Magnotta, and Cameron Pelletier,] and we are part of a project team from Worcester Polytechnic Institute. We are working with the Consumer Product Safety Commission (CPSC) to evaluate the safety and health risks associated with 3D printing pens. To accomplish this, we have been gathering information from current or past 3D printing pen users.

We would like to ask you a few questions about your familiarity with the pens, overall experience, and any issues/safety hazards you have come across. You may also express any opinions you may have. We want to clarify that your participation in this research is voluntary, you may end your participation at any time, and you are not required to answer every question in the interview. Your answers will be kept confidential.

<u>Interview Questions</u>

Q1. Are you an educator? What subject and grade level do you teach?

a. If yes, go to question 2
b. If no, go to question 3, disregard questions 9-11

Q2. Did you use a 3D pen?

a. If yes, did you use a 3D pen prior to, during, or after introducing your students to one?
    i. Then answer all the questions below.
b. If not, go to question 4.

Q3. Tell us why you used a 3D pen.

a. Was the 3D pen your primary tool or was it a complementary tool for more complex projects?

Q4. What brand of 3D printing pen and filament did you (or your students) use?

a. Why did you choose this one?
b. Did you consider any other brand?
c. How would you rate the pen and filament on a scale of 1-5
    i. 1 - terrible quality
    ii. 5 - excellent quality
d. What factors influenced your rating?

Q5. On average how long did you use the pen per session?

APPENDIX A: INTERVIEW STRUCTURE

Q6. As you know we're particularly interested in pen safety. What can you tell us about that?

   a. Have you come across any common issues?
      i. Fumes? Jamming? Burning of user's hands/fingers? Potential harm to people other than the user?

Q7. What safety dangers or hazards were you warned of, if any?

   a. If you were warned of any dangers or hazards,
      i. By what means were you warned? (an operating manual, a label on the pen, warning label on the side of the package, etc)?
      ii. What precautions were you encouraged to employ?
      iii. What other safety hazards would you warn another 3D pen user about?
   b. If you were not warned of any dangers or hazards,
      i. What are some issues you would warn a new user about?
      ii. How would you like to be warned about safety hazards? (A warning label, an online safety course, etc)?

<u>The following questions pertain more to your students' experiences.</u>

Q8. What were the safety concerns or issues from your students when using 3D pens?

Q9. Did you warn your students of any safety hazards before using the pens?

   a. If so, how did you warn them? (Demonstration, quick verbal warning, etc)?
   b. If not, do you wish you had?

Q10. Where were the students when you used the pens? (windows open, AC fans on, fume hood, room near max capacity? Multiple pens being used? Any other conditions?)

<u>Final Questions</u>

Q11. What are your thoughts on children, between the ages of 6 and 12 years old, using 3D pens for educational or recreational purposes?

Q12. We are looking to contact other individuals or organizations who have experience using a 3D pen. If you know of any, and feel comfortable sharing, can you give us their name and email address where we can contact them.

APPENDIX B: HEALTH AND SAFETY FACT SHEET

The Health and Safety Fact Sheet can be seen on the following page.

HEALTH AND SAFETY RECOMMENDATIONS FOR 3-D PRINTING PENS

3-D printing pens are crafting toys that are also handheld additive manufacturing devices. They extrude molten plastic allowing freehand 3-D creations. 3-D pens have recently become more widely used in schools and homes.

Safety Hazards

Burn Hazard:

- Heating element used to melt down filament.
- Molten filament extruded from pen.

Choking Hazard:

- Some pens have small removable parts.
- 3-D creations may also be or contain small parts.

Chemical Hazards:

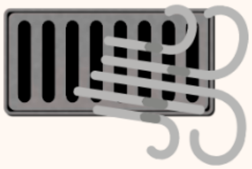
- Filaments can emit ultrafine particles (UFPs) and volatile organic compounds (VOCs) when melted.
- Touching filament before it has fully melted and cooled down may leave chemical residue on skin.

Safety Precautions

- Use pen with internal heating element to reduce burn hazard.
- Use filament with lower recommended melt temperature.
- Use material that have can emit less. Initial data suggests that ecoplastic filament can emit less than polyactic acid (PLA) filament which emits less than Acrylonitrile Butadiene Styrene (ABS) filament.
- Use scissors to remove excess filament from the tip of pen.
- Check for broken parts before use.

Here are some recommendations to consider when using a 3-D printing pen

Use under adult supervision.



Use in well ventilated area.

Use personal protective equipment such as heat resistant gloves, fingerstalls, or safety glasses.

Use at recommended filament temperature.

Wash your hands after use.

Clean the working area after use.

Don't touch heated tip of pen or melted filament.

Don't eat the filament.

Don't put the pen near your face when it is being used.

Don't touch face while using pen.

APPENDIX C: SAMPLE SCHEDULE AND ANALYSIS

We worked with the CPSC staff and an industrial hygienist to create an emissions sampling plan.

Sample Description	Personal or Area	PLA or ABS or ECO	High or Regular Temp	VOC Air	Metal Inorganic Air	Particle	Dermal
1) EcoPlastic, Small Room	P	ECO	Reg	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
2) Mynt- 3D, Small Room	**P**	**ABS**	**High**	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	Pre and Post Wipe Samples (2), Total mass and Metals-Scan targeted Small room after one sample
3) Mynt- 3D, Small Room	P	ABS	Reg	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
4) Mynt- 3D, Small Room	A	ABS	High	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
5) Mynt- 3D, Small Room	A	ABS	Reg	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
6) Mynt- 3D, Small Room	P	PLA	High	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
7) Mynt- 3D, Small Room	P	PLA	Reg	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
8) Mynt- 3D, Small Room	A	PLA	High	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
9) Mynt- 3D, Small Room	A	PLA	Reg	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
10) Mynt- 3D, Large Room	P	ABS	High	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	Pre and Post Wipe Samples (2), Total mass and Metals-Scan targeted Large room all day
11) Mynt- 3D, Large Room	P	ABS	Reg	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
12) Mynt- 3D, Large Room	A	ABS	High	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
13) Mynt- 3D, Large Room	A	ABS	Reg	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
14) Mynt- 3D, Large Room	P	PLA	High	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
15) Mynt- 3D, Large Room	P	PLA	Reg	NIOSH 1501	NIOSH 7303	Ultrafine/Nano Personal Sampler	n/a
16) Mynt- 3D, Large Room	A	PLA	High	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
17) Mynt- 3D, Large Room	A	PLA	Reg	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
18) Background Air small room	A	n/a	n/a	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a
19) Background Air larger room	A	n/a	n/a	NIOSH 1501	NIOSH 7303	TSI P-TRAK 8525 Ultrafine Particle Counter TSI AeroTrak 9306 Optical Particle Counter	n/a

Table 2. Sample Schedule and Analysis. The gray shading indicates combinations that are lower priority and may not need to be sampled. Sample 2 is bolded because it is expected to result in the highest levels