

How to Make PPE: The Unity Mask

**A Step-by-Step Guide to Create a
P100 Respirator Mask With a 3D Printer**

Created by: Steve Martin, DO and James R. Latronica, DO

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Introduction

This project was initially conceived as an emergent, rapid response to the devastating lack of personal protective equipment (PPE) nationwide in the United States. After seeing heartbreaking images of health care workers forced to resort to bandanas for “protection,” we started brainstorming ideas for how we could help. As the now famous N95 respirator mask was a critical piece of the PPE puzzle that was in short supply, we began investigating the specifications of the N95 and comparing/contrasting to “commercial” respirators and filters.

The N95, when fitted properly, should theoretically capture 95% (thus the N95 moniker) of airborne microparticles, including viruses. Respirator filters used in commercial applications—specifically the P100 we used for our project—should theoretically capture 99.97% of airborne microparticles.

PPE used in medical facilities is regulated by the FDA, whereas respirators used in industrial applications are regulated by the National Institute for Occupational Safety and Health (NIOSH). Thus, we have no definitive 1:1 correlation in terms of advice on how long the P100 filters should be considered viable in a health care setting, or how they might best be decontaminated.¹

However, there are past references in the literature on both the theoretical, as well as the practical application and simulated viral load challenge of commercial respirator filters for use in the health care setting. Based on the construction of the material as well as experimental analysis, we believed there to be a significant enough amount of evidence to construct a non-porous, 3D-printable respirator shell that could accept P100 filters, which at the time of this writing are still widely available though at increased cost in some cases. We created a prototype and, thus, the Unity Mask was born.

For decontamination, we used guidance from Viscusi, *et alia* wherein various methods of P100 decontamination were experimented with, side by side with N95 masks.² They concluded that ultraviolet germ irradiation (UVGI), ethylene oxide (EtO), and vaporized hydrogen peroxide (VHP) were the most promising and caused no discernible damage to either the N95 or the P100 models. They also attempted bleach, which successfully decontaminated the respirators, but leave a bleach scent. With bleach being the most widely available of these decontamination options, it seems reasonable that using a bleach-based wipe or solution—as long as the scent is tolerable—would be a cheap and efficient method.

We do encourage anyone partaking in this project to check with their infection control department as well as their occupational health department, as various hospitals will have different levels of comfort with non-FDA approved PPE. However, for areas hardest hit and in the most desperate need, we cannot fathom that a fit-tested and properly decontaminated Unity Mask respirator could possibly be *inferior* to improvised face covers, or even barrier surgical masks. In addition, for wear in public, outside the confines of the hospital, the Unity Mask would certainly be an improvement over homemade masks. If you’ve read this far and you’re still interested, we will explain the procurement of the necessary equipment, and then we’ll get started with instructions for printing.

To get started making a basic Unity Mask, you will need approximately \$3,450 for the printer, software and mask supplies. To make a custom Unity Mask, it is estimated you will need \$5,600. Once you have this equipment, you can make multiple masks. In this manual, we outline supply costs for the mask materials, as well as alternative printers and printer upgrades you can purchase.

¹ Gardner, Paul D., et al. “Viable Viral Efficiency of N95 and P100 Respirator Filters at Constant and Cyclic Flow.” *Journal of Occupational and Environmental Hygiene*, vol. 10, no. 10, 2013, pp. 564–572., doi:10.1080/15459624.2013.818228.

² Viscusi, Dennis J., et al. “Evaluation of Five Decontamination Methods for Filtering Facepiece Respirators.” *The Annals of Occupational Hygiene*, vol. 53, no. 8, 2009, pp. 815–827., doi:10.1093/annhyg/mep070.

Budget

We have included an itemized budget sheet with options to create a basic or advanced mask with basic or advanced supplies. This instruction manual provides guidelines for printing on the Creality CR-10S Pro V2 using Simplify3D as the software. Other printers and software can be used, but keep in mind that the specific instructions will vary based on the model of printer and type of software you use.

We have also included categories of “Advanced” supplies, mainly that are meant to increase printing speed and quality. They are not strictly necessary, and we printed perfectly functional Unity Mask respirators without the upgrades. In addition, you will find a category for “Advanced for Personalized Masks.” This part of the project is far more experimental, and we will not be including a tutorial for this aspect at this time. The basic idea is that a 3D scanner can be used to scan a person’s face then, using 3D modeling software, a perfect mold of their face could be produced, either for the Unity Mask itself or for a flexible insert. This aspect is still a work in progress.

3D-Printed P100 Compatible Mask Supplies (Basic)	Price	Amount	Total*	Description/Misc.	Where to Purchase
Acer Predator Triton 500	\$ 1,899.00	1	\$ 1,899.00	Laptop w/requisite processing power for handling 3D design – may try alternates	Amazon
Creality CR-10S Pro V2	629.99	1	629.99	3D printer with auto-levelling features (need the V2 for auto-level to be included)	Amazon/eBay/creality3dofficial.com
Simplify 3D Software	150.00	1	150.00	Allows for import of STL files (this is how the computer “talks” to the printer) – other programs will work, but our tutorial is specific to the use of this program	Simplify3D.com
HATCHBOX PLA 3D Printer Filament	199.99	1	199.99	Base printing material (1 spool = 20–40 masks) – may try alternate brands	Amazon
CyberPower CP1500PFCLCD PFC Sinewave UPS System, 1500VA/1000W	199.99	1	199.99	Uninterruptible power supply; equipment protection specific to 3D printing requirements	Amazon
3M P100 Filters	4.49	2 per mask	8.98	Commercially available respiratory filter – prices now variable	Amazon/Home Depot/Lowe's/WalMart
Dritz Pry-9507B Non-Roll Elastic, 1", Black	6.50	1	6.50	Strap material – encourage to try alternates based on comfort and fit test	Amazon
CPR Mask Replacement One-Way Valve - 10 Pack - Archer MedTech Brand	9.95	1	9.95	One way valve that can be installed in the mask	Amazon
Neoprene Rubber Door Weather Stripping	10.95	1	10.95	Padding material – encourage to try alternates based on comfort and fit test	Amazon/Home Depot/Lowe's/WalMart
BOENFU Wire Cutters, Flush Cutter 5-Inch	9.89	1	9.89	For cutting/trimming filament (regular scissors work poorly)	Amazon
Printer Maintenance/Restocking	300.00	1 per ~40–100 masks	300.00	Printer bed cover, extruder, nozzle, and filament are all consumable or semi-consumable	Various
Neiko 01407A Electronic Digital Caliper	22.95	1	22.95	Micrometer to measure filament, 3D printed components, etc.	Amazon
			\$3,448.19*	This total price gets you up and running to make one mask every 4–8 hours, depending on settings	

*Prices are estimates only, as of April 2020

3D-Printed P100 Compatible Mask Supplies (Alternate Printer)	Price	Amount	Total*	Description/Misc.	Where to Purchase
Creality Ender 3 Pro	\$ 269.99	1	\$ 269.99	3D printer – fewer features than CR-10S	Amazon/eBay/ Creality3DOfficial.com
Creality 3D BL Touch Auto Press Bed Leveling Kit	57.99	1	57.99	auto-leveling kit – requires manual installation	Amazon/eBay
BMG Dual Drive Extruder	89.99	1	89.99	speed/multi-material printing – included with CR-10, not Ender 3 Pro	Amazon
Creality 3D Ender 3 Upgrade Motherboard V1.1.5	38.99	1	38.99	quieter/faster printing for Ender 3	Amazon
			\$ 456.96*	This total price gets you a printer close to functionality of CR-10S, but requires more assembly	

3D-Printed P100 Compatible Mask Supplies (Advanced)	Price	Amount	Total*	Description/Misc.	Where to Purchase
Genuine Bondtech BMG Extruder	\$ 89.99	1	\$ 89.99	Increased printing speed/accuracy	Amazon
Creality 3D Printer Enclosure Fireproof and Dustproof 3D Printer Tent	119.99	1	119.99	Protects from dust and creates more even temperature	Amazon
Tresbro Creality CR-10 Glass Bed	27.99	1	27.99	Improved adhesion of filament to bed (potentially fewer malfunctions)	Amazon
Micro Swiss All Metal Hotend Kit	63.50	1	63.50	Faster heat dissipation for more even printing (potentially fewer malfunctions)	Amazon
IPSG 3D Filament Storage Box	59.99	1	59.99	Keeps filament dust free and dessicated (moist filament won't print well)	MicroCenter.com
			\$ 361.46*	This total price may improve your printing success and minimize waste	

3D-Printed P100 Compatible Mask Supplies (Advanced for Personalized Masks)	Price	Amount	Total*	Description/Misc.	Where to Purchase
2019 EinScan-Pro+ with R2 Function Multi-Functional Handheld 3D Scanner	\$ 4,769.00	1	\$ 4,769.00	3D facial scanner for individualized mask customization	Einscan.com/Amazon/(call or Shining3D directly for possible demo model trial)
Mosaic Palette 2 Pro (1.75mm) Palette 2 for Multi-Material 3D Printing on 1.75mm Printers	799.99	1	799.99	Allows for multi-material printing (e.g. flexible plastic printed directly on rigid plastic)	Amazon
NinjaTek 3DNF0117505 NinjaTek NinjaFlex TPU Filament, 1.75mm	45.00	1	45.00	Flexible plastic filament for form-fitting shapes	Amazon
			\$ 5,613.99*	This total price allows you to scan faces, and print flexible material onto rigid material	

*Prices are estimates only, as of April 2020

Troubleshooting

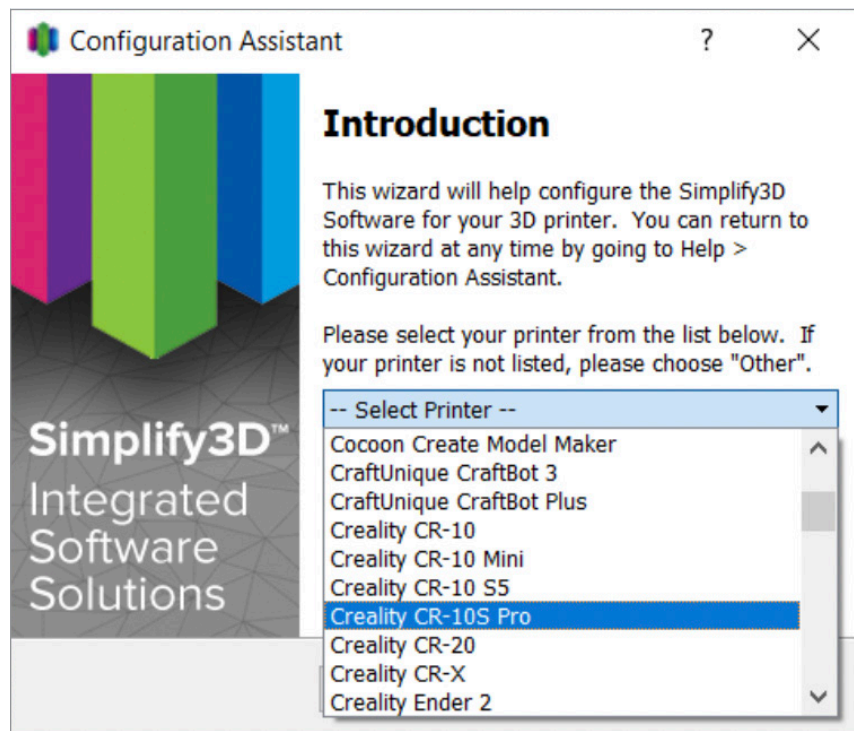
Part of the reason we chose the Simplify3D software is because the program has a wide user base, and their website has a robust troubleshooting guide, written in a very accessible way and with images for comparison. If you find yourself having issues with print quality, we suggest you use their Print Quality Guide: <https://www.simplify3d.com/support/print-quality-troubleshooting>.

The guide can help you even if you end up using a different type of software.

Now, without further ado, let's get to printing!

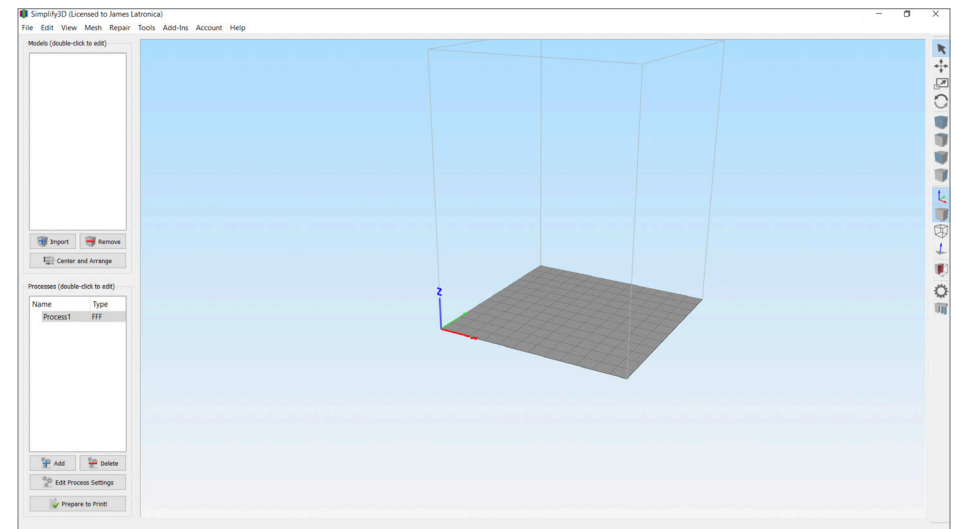
Printer Assembly

Please refer to the instructions included with your respective printer, as the instructions therein are more thorough than we can provide. If your printer model does not come equipped with a BLTouch Automated Levelling System, we strongly suggest the purchase and installation of one, as it makes printing a much faster, simpler process. The instructions for this process will likewise come from the manufacturer. If you are using the CR110S Pro (not the V2) the built-in inductive auto-leveler is sufficient. No matter which printer you choose, after assembly, make sure to level the print bed and run a test print—which for Reality printers can be found on the included MicroSD card.

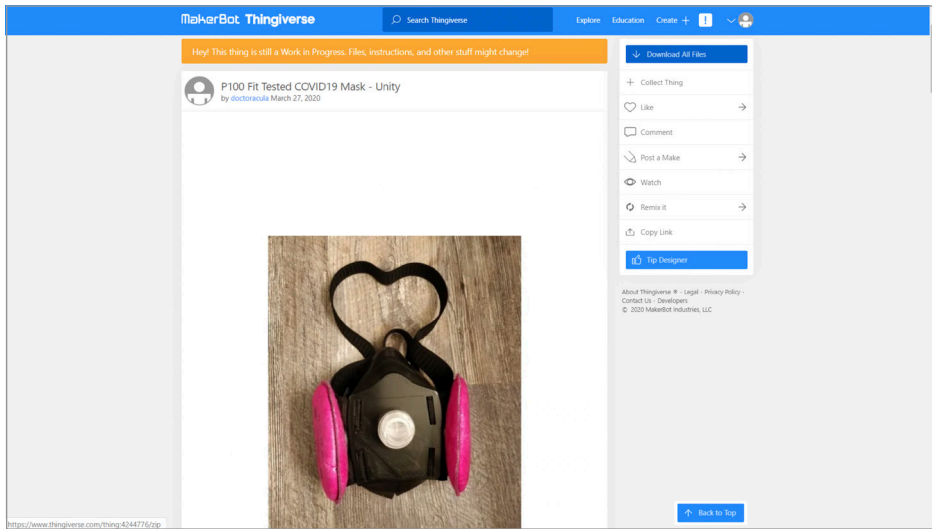


Initial Computer and Printer Setup

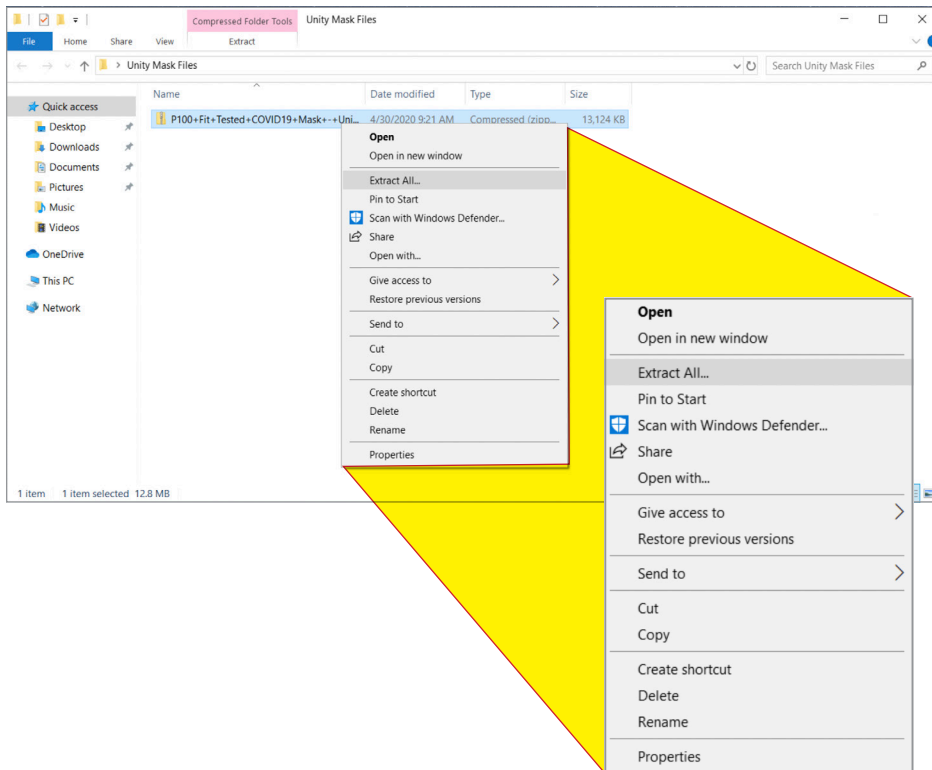
1. Purchase and install Simplify3D — upon first starting the program, a Configuration Assistant will help you with initial setup.
2. Select your printer model from the drop-down list.
3. The program will open, and you will see the “home screen” of the Simplify3D program. Find the Unity mask template on Thingiverse. Image of the correct page is below.



4. Link: <https://www.thingiverse.com/thing:4244776>

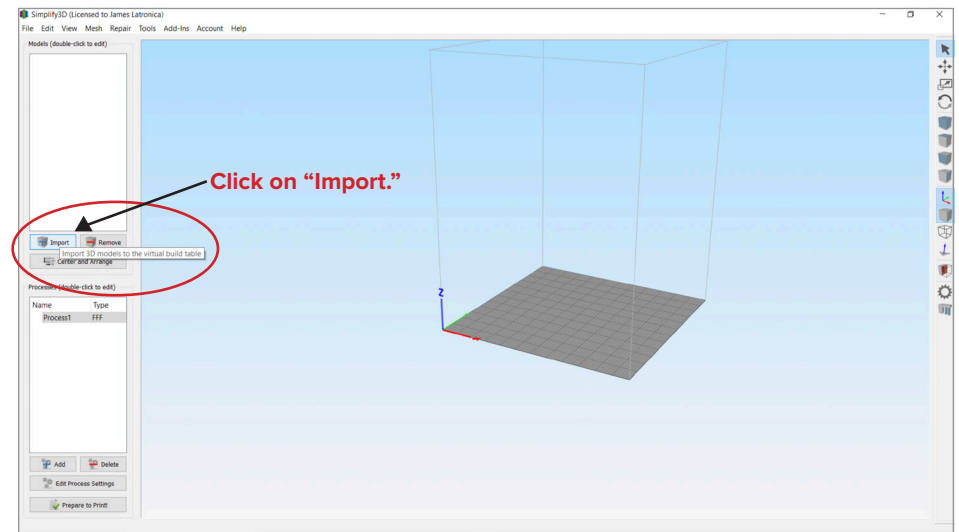


5. The downloaded files will be in a .zip format. Unzip the files to a folder on your computer.

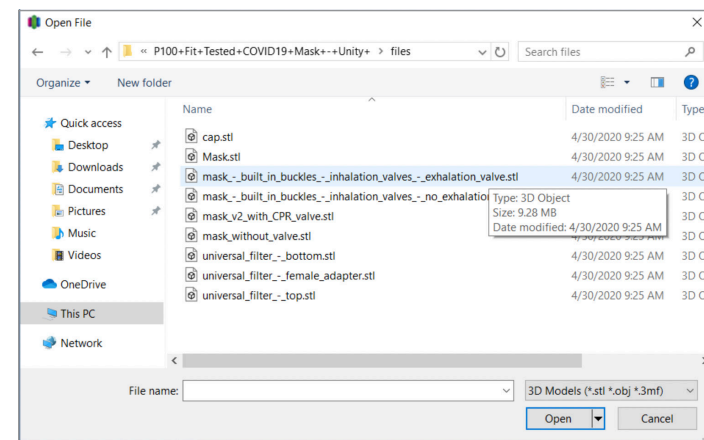


6. There are multiple files within the folder. Specifically, there are two main mask types. One type can have a one-way CPR valve installed. (This is not necessary but may add to comfort.) The other type has a flat front, and does not accept a CPR valve. They are differentiated by the file name, and should be self-explanatory: “Unity Mask with CPR valve.stl” or “Unity Mask without CPR valve.stl”. Both are functional and can be fit tested. You can also rename these files for convenience after downloading.

7. Now that you’ve downloaded and located the mask files on your computer, you’re ready to import the file into Simplify3D. Go back to your “home screen” in Simplify3D, and click on the “Import” button on the left side of the screen, near the middle.

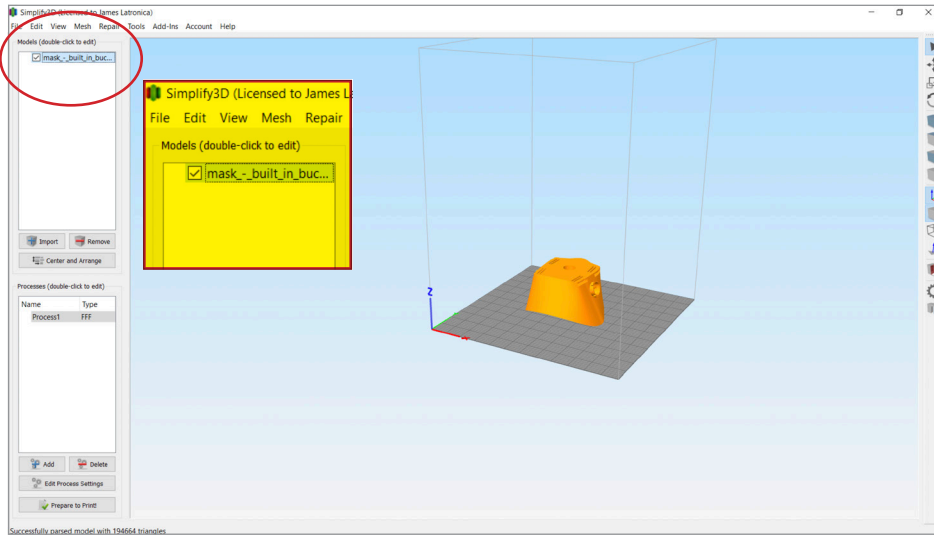


8. Select the folder where you previously unzipped the STL files to.

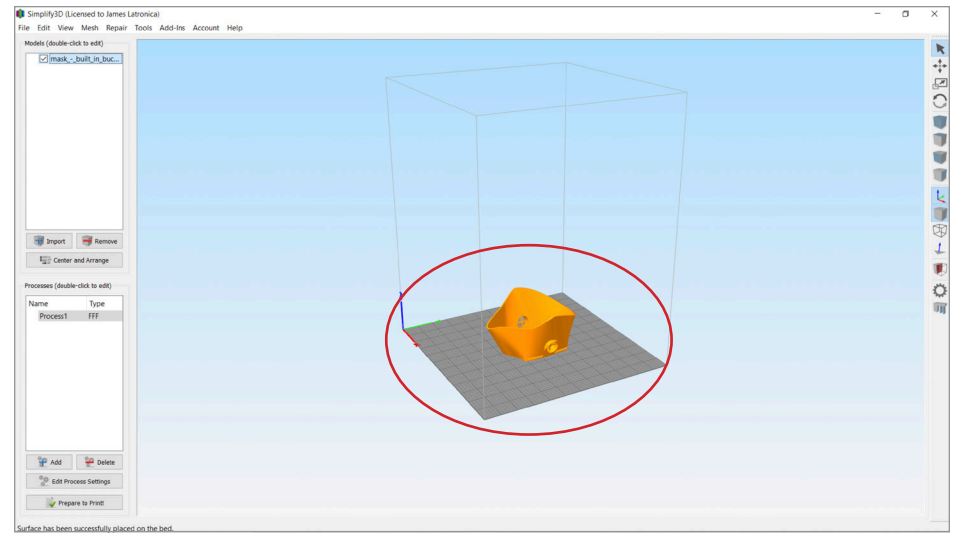


9. Double click on the file name, and you'll be brought back to your "home screen," and a 3D representation of the Unity mask will appear on the grid.

10. In general, when 3D printing, you want a flat surface laying on the printer bed. To accomplish this in the Simplify3D program, press Control + L, then click on the front plate of the mask. In the image below, the face is pointing upward.



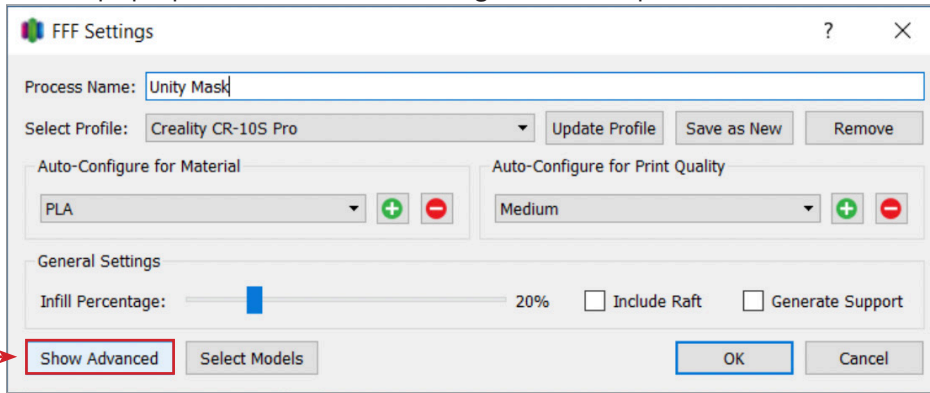
11. The front plate of the mask should now be laying flat on the grid.



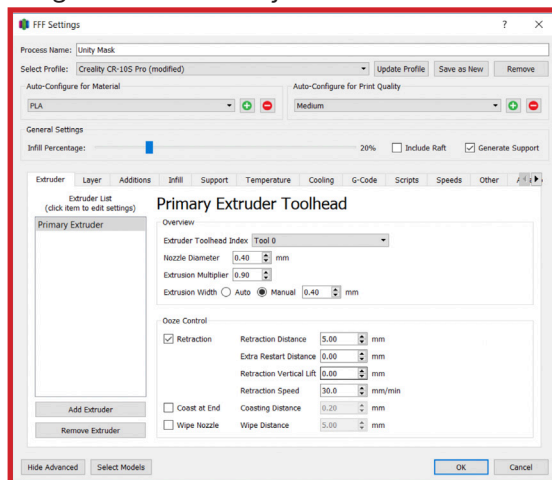
12. Great! We have our model, it was able to be imported, and it's correctly oriented. The next step is to tweak the settings of the printer using Simplify3D so we can ensure a successful print.

Process Settings

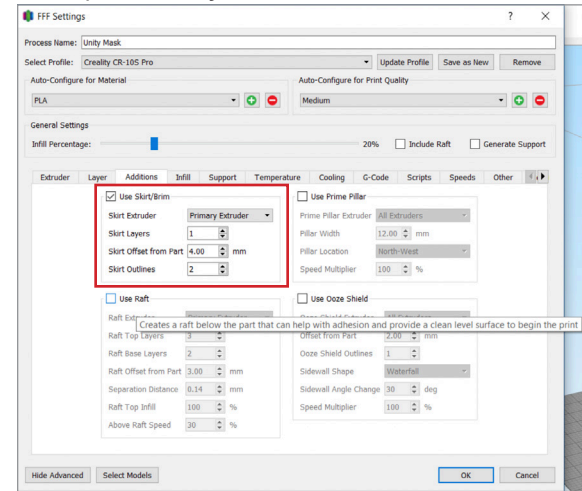
1. On the left side of the screen, below the “Import” button you previously used, you will see a window with a gray bar, in which you will see the words “Process1.” Either double-click that gray bar, or select the “Edit Process Settings” button in the lower left. A screen will pop up that reads “FFF Settings” on the top.



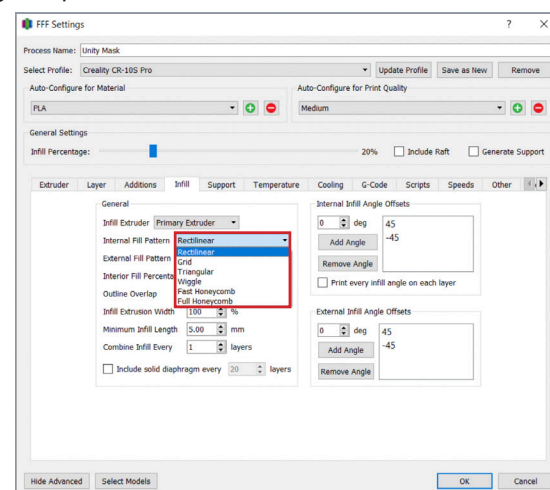
2. You may be able to use the presets shown in this window to successfully print a mask. **If you'd like to attempt it this way, skip to Step 11 of this section.**
3. We do recommend some changes to maximize your chances of a successful print. For those who would like to make these changes, select the “Show Advanced” button in the lower left hand of the FFF Settings pop-up window. The window will expand and show various tabs with settings that can be adjusted.



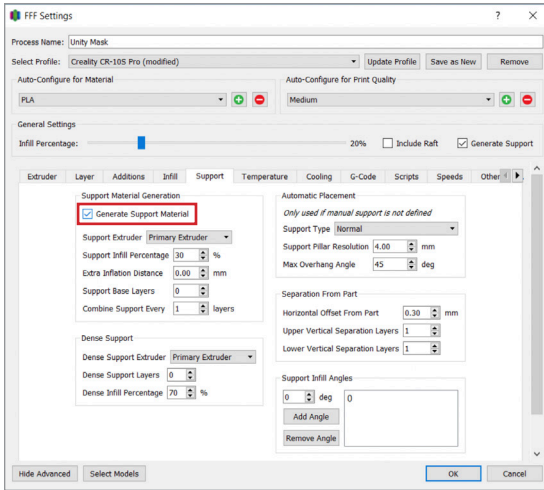
4. You will likely *not* need to change anything in the “Extruder” or “Layer” tabs. Select the “Additions” tab first. **We generally suggest selecting the “Use Skirt/Brim” checkbox.** This makes an outline of your model, and allows the extruder to “warm up” and produce more consistent lines. “Use Raft” can likely remain unselected. If you have problems with the initial layers of your mask adhering to the printer bed, this is an option to try.



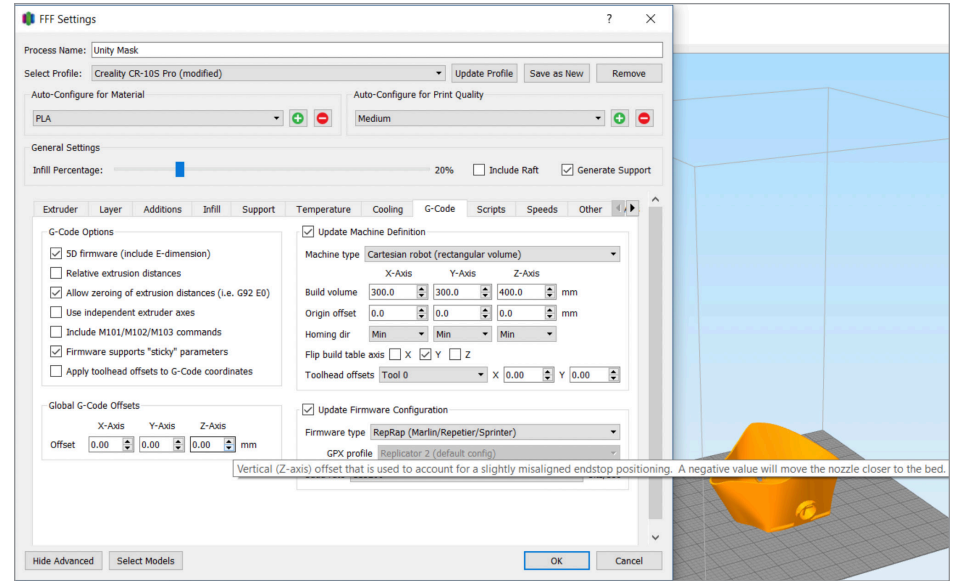
5. The “Infill” tab is also one in which you will likely not need to make changes. Using “Rectilinear” internal and external fill pattern has worked well for us. If you have issues thin layers, consider trying “Honeycomb.” Keep in mind this will increase the time and filament used for your print.



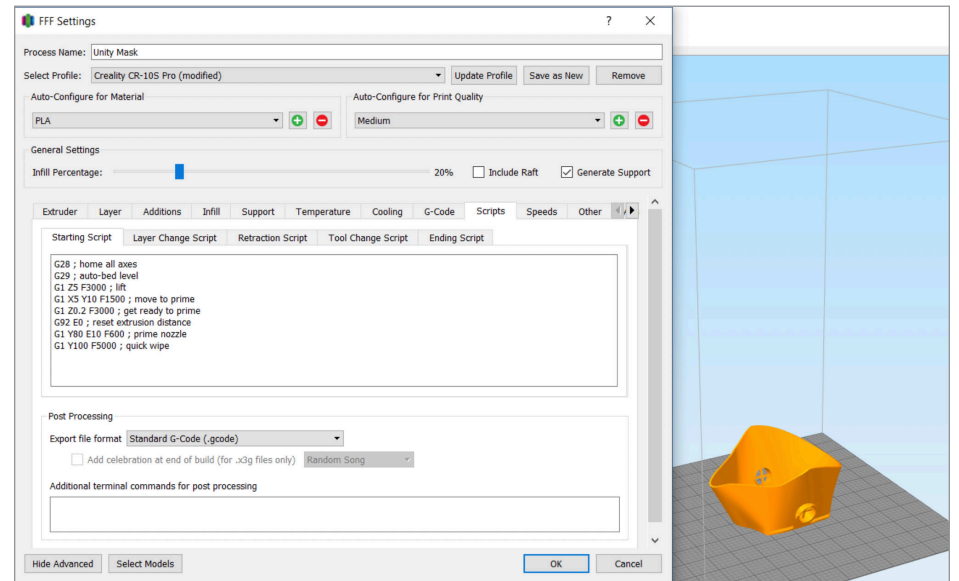
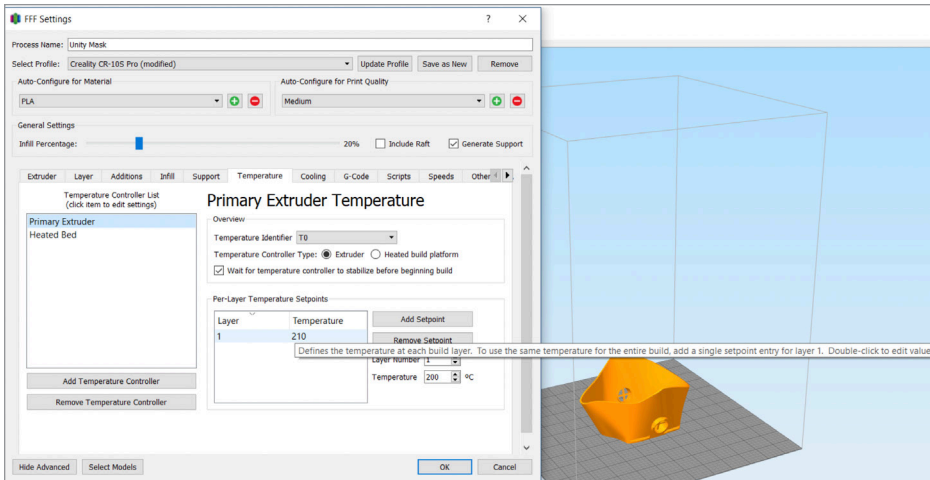
6. The “Support” tab is one you will want to select and change. Click the tab and tick the box where it says “Generate Support Material.” This will allow the computer to automatically create small geometric shapes to keep your mask supported—especially the filter intakes—while it prints.



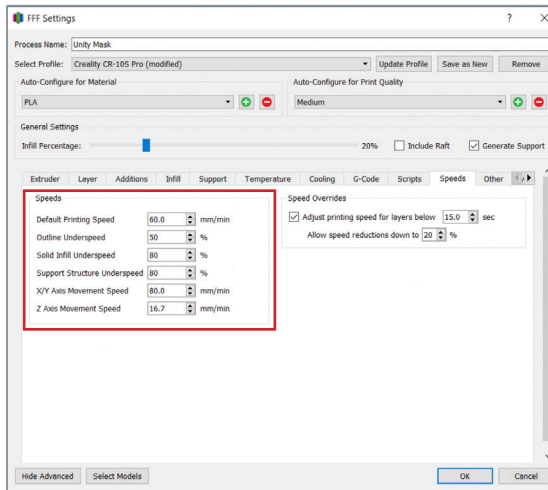
8. The “Cooling” tab is likely sufficient at default. The “G-Code” tab and “Scripts” tab are likewise probably sufficient at default. The “G-Code” and “Scripts” tabs are where more advanced techniques and settings can be modified. For more information on that, we would refer you to Simplify3D’s own FAQ section, as it is far more detailed and robust than what we can provide here.



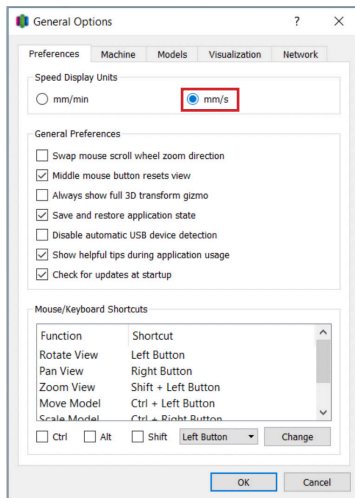
7. The “Temperature” tab allows you to change the temperature of the extruder as well as the printer bed. The defaults of **210°C for the extruder and 60°C for the printer bed** are generally sufficient for the PLA filament we are using.



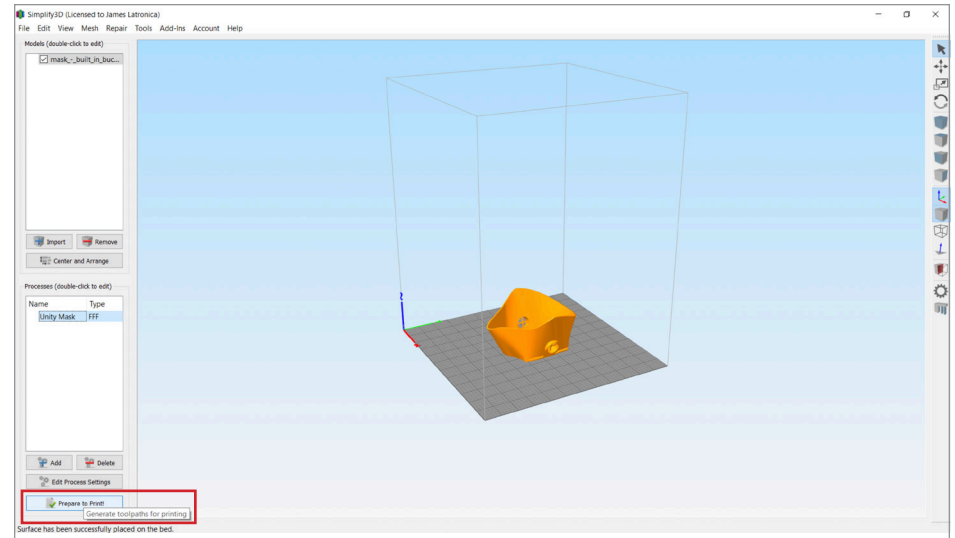
9. Depending on print settings, upgrades, and accessories, print time can vary widely, and is largely a function of print speed. For this mask, **we recommend starting your print speed to 50-60mm/second** and experimenting with speeds as you become more comfortable with printing.



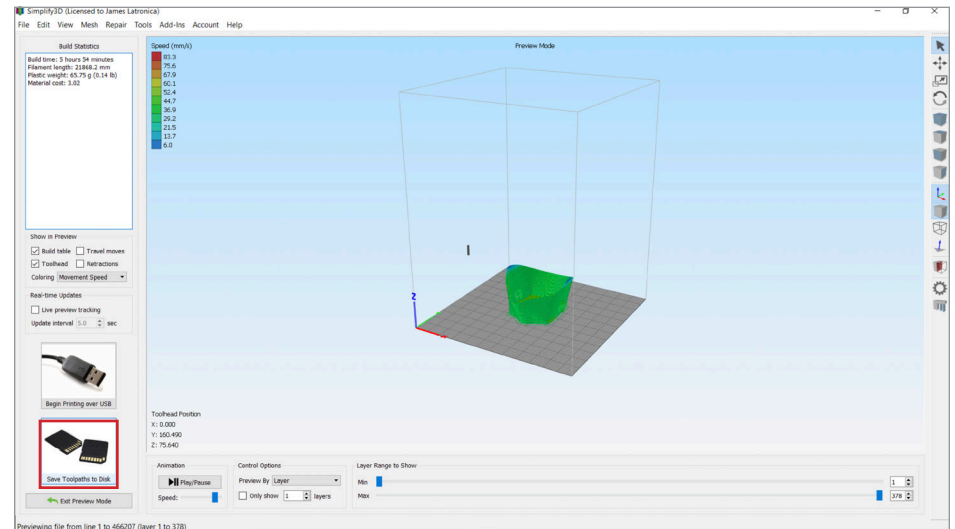
10. Your default unit of print speed measurement may be set to “mm/min(ute)” as opposed to the “mm/s(econd)” we recommend. To change this setting, click the “Tools” menu at the very top of the home screen. Then select Options, and the “General Options” menu will open. The very first heading will read “Speed Display Units” and you can **tick the “mm/s” circle as opposed to the “mm/min” circle**.



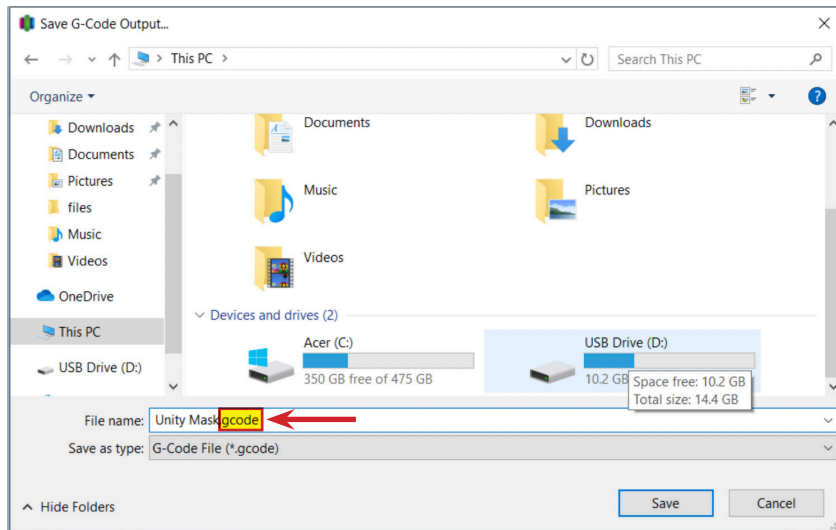
11. Finally, you’re ready to start printing! On the “home screen” you will find the “Prepare to Print!” button on the bottom left.



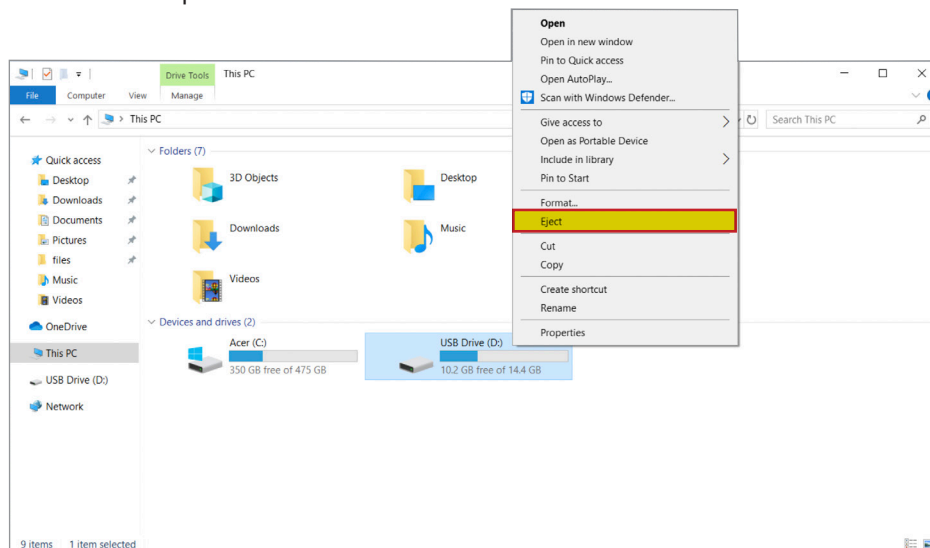
12. Click the button, and you will be taken to Preview Mode, where a mesh model showing the layering of your mask will be visible, along with the support structures that were automatically generated. You’ll see two options on the bottom left, “Begin Printing over USB” and “Save Toolpaths to Disk.” **We suggest using “Save Toolpaths to Disk”** as this allows you to save your files to a MicroSD card, and removes a potential point of failure by not relying on a connection to your computer.



13. Once you select “Save Toolpaths to Disk” select the drive that contains your MicroSD card. (The Creality CR-10S Pro comes with a MicroSD card reader, but you will have to provide the MicroSD card yourself). You can rename the file—in the image below it is renamed “Unity Mask”—**but make sure to keep the .gcode file extension that follows the name.** We also suggest using a short name, as the printer itself will only display the first ten characters of a file name.

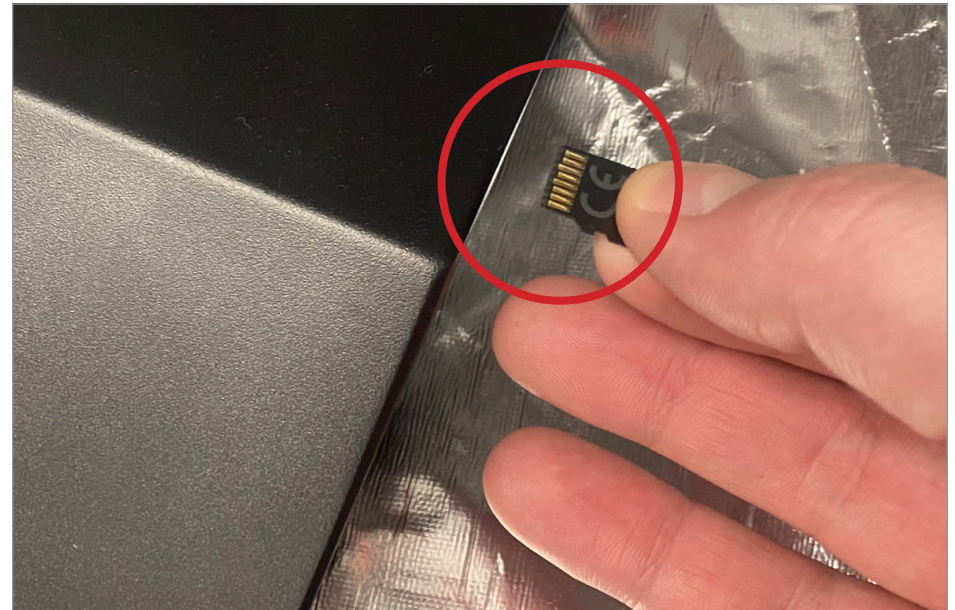


14. After the file is saved, safely eject the MicroSD card to avoid data corruption.



Printing

1. Insert the MicroSD card (gold contacts facing upward) into the MicroSD slot on the right side of the printer, near the front. Press firmly, and you will hear a click, signaling that the card has been inserted fully.



2. On the front touchscreen of your printer, select the “Print” option on the left.



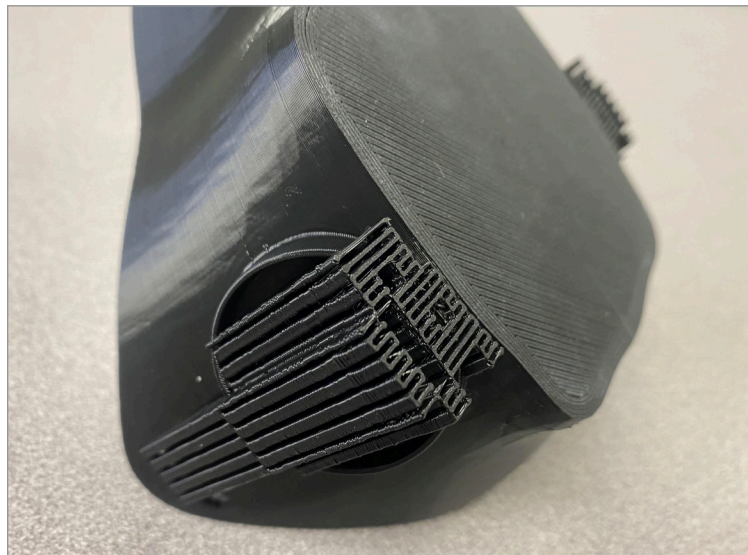
3. Select the file from the scrollable menu that appears on the left, and press the print button on the lower right portion of the touchscreen.



4. From here, your printer will warm up, auto-level (if BLTouch is installed), and begin printing. Congratulations, you're on your way to your first mask!

Finalizing the Unity Mask

1. Remove the printed mask from the bread, and remove the small columns of support structures, most of which can be found around and inside the two openings for the filters. You may need to use your wire cutters for this.



2. If you've printed a mask with an opening for a one-way CPR valve, you can simply insert the valve into the opening on the front. The opening is designed so that the valve only needs to be pushed in a short way (~3mm).



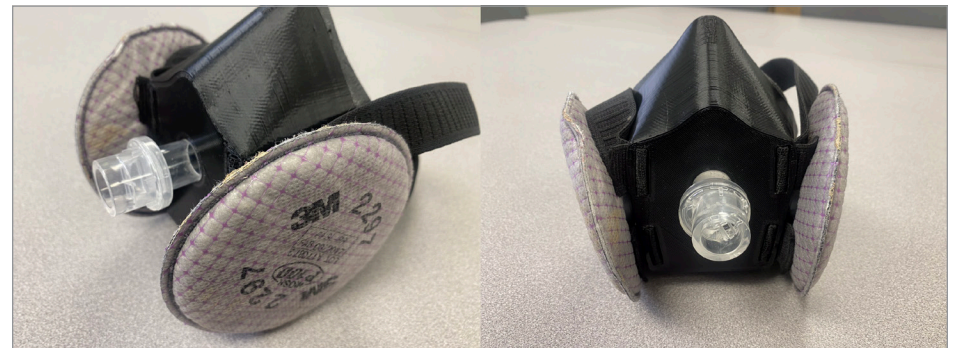
3. The strap material we used is simple, 1" width elastic fabric purchased in rolls. It should be threaded "through and through", by inserting one end into the slot closest to your face, then bringing it under and out the slot furthest from your face, and finally bringing it back through the slot closest to your face. This allows the tightness of the strap to be adjusted most easily and creates a secure fit. In our experience, about 40cm. (16 inches) worth of elastic creates a secure fit while leaving room for adjustments.



4. The choice of padding material is up to you. We have had success with two types of weather stripping, both of which are widely available either online, at DIY stores, or even big box stores. However, **the adhesive present on the stripping is likely not sufficient in the setting of extended wear.** We suggest applying an additional adhesive directly to the mask, securing the weather stripping, then allowing it to dry overnight while being clamped with binder clips (the type you'd find in an office). We used clear Gorilla Glue with great success.



5. The final step is attaching the P100 filters to both sides of the mask. For the sake of convenience, this can be done either before or after placing the mask on your face. As mentioned above, govern the regulatory bodies that traditionally given the use of filters like the P100, we do not yet have clear guidelines on use. The packaging on most brands suggests 40 hours of use per filter once opened, and 40 days of viability if left unopened, but given the ability to sanitize—either by heat or by chemical wipe—we suspect that the true "shelf life" may be considerably longer. Note that the filters in the image are expired filters, used for modeling. Viable filters are generally a bright pink color.



6. Congratulations! You now have a fully functional personal respirator! Don't forget to have it fit tested by your Occupational Health department.

Acknowledgments

This project would not have been possible without generous grants from the Pennsylvania Osteopathic Medical Association Foundation and the American Osteopathic Information Association (AOIA). We would like to extend our gratitude and appreciation for their confidence in this project. These groups have made us even prouder to be osteopathic physicians.

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Finally, we'd like to thank each of our wives, who have put up with some combination of long nights, crazy ideas, daily deliveries, or technology noises for going on two months now.

Steve Martin, DO

James R. Latronica, DO

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Disclaimer

This information, provided by the American Osteopathic Association (AOA) and the American Osteopathic Information Association (AOIA) for the “How to Make PPE: The Unity Mask; A Step-by-Step Guide to Create a P100 Respirator Mask with a 3D Printer,” was created by third-party individuals with knowledge regarding the creation of healthcare masks via three-dimensional (3D) printing. However, the information found within the written manual and video presentation is for general informational purposes only. All information within the written manual and the video is provided in good faith; however, the AOA and AOIA make no representations or warranties of any kind, express or implied, regarding the accuracy, adequacy, validity, reliability, availability or completeness of any information within these materials.

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