A Proposal to Improve the 3D Printing at the inVenTs Studio

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Overview of 3D Printing

3D printing is a method of additive manufacturing that allows users to create complex geometries within a matter of hours depending on the size. This is useful for the user when simple 2D manufacturing might not be possible. For example, users can create a small boat with various 3D curves that a laser cutter would not be able to produce without multiple different layers which would reduce quality. Due to its inherent additive style of manufacturing, 3D printing also has very little waste involved compared to using a CNC machine or laser cutter, since it only prints what is required of the model. CNC machines and laser cutters are subtractive manufacturing where it would remove material from whatever it is cutting from. 3D printing compliments these 2D manufacturing machines and are helpful when prototyping various designs.

3D Printing at inVenTs Design Studio

The current situation at the Studio has students following a QR code in order to access a link. At this link, it has the student fill out a form containing various questions such as: How big is the model? Who created the model? And what is its purpose? It also has the student upload the model as an .stl file and a picture of the model. There is no option to choose color, plastic type, and there is no real ability for the student to optimize what exactly they are looking to do. Students also have a printing limit of exactly 4”x4”x4”. Of course there is the ability to go slightly over that, but that is up to the GA’s discretion. Once the form is submitted, on average, it takes seven days for the model to be printed and received by the student. Seven days is a massive difference from the approximated 12 hours that a 4” cube should take to print. For something that is commonly used for rapid prototyping, seven days is quite slow and could be the difference between using the 3D printer at the inVenTs Studio versus Frith or not doing the idea at all.

This wait period is largely due to the current operation of the 3D printing queue in the studio. At the moment, only 1 of the 3 GAs has access to the queue and is trained and knowledgeable on the operation of the 3D printers. Since the GAs are on a rotating schedule, this leaves only 2 days a week that prints can get processed. Depending on the amount, size, and detail of the prints in the queue,about 4 or so prints can fit on the build plate, and print in approximately 4-12 hours. Since the Studio is only open for five hours a day, the prints could go on overnight and be ready to use the following day. However, since the current knowledgeable GA is in for only 2 days a week, the prints sit on the printers and do not become available to the students until their next shift, resulting in a lengthy wait time. This system has quite a bit of inefficiency, and that could be resolved.

Areas for Improvement in the Studio's 3D Printing Service

3D printing is an extremely useful tool in the prototyping and development of engineering projects, so it is important that this service is not only available but efficient in a maker space like the inVenTs Studio. While this service is currently available in the studio, it is not nearly efficient enough to be utilized to its full potential. An important, and simple, improvement that can be made to this service at the studio is the return time for printing requests from the students. A shorter return time can enable students to better meet prototyping and development deadlines in project based classes - such as Engineering 1216, design teams, and even personal projects. Moreover, enabling students to utilize this important resource can, and likely will, increase student engagement with the studio as they realize the value and availability of the full resources of the studio available to them for use.

Since the inVenTs Studio's main purpose is to allow the students of Galipatia access to resources and materials for personal projects and experiential learning, having options for creativity and design are also important. Currently, prints are done in only white colored PLA filament - which is a good generic to have for easy painting and common use, however, having access to other filament colors and types does allow for more creativity. Basic and inexpensive paints wear off fast on textured and frequently used prints, and they can be unsafe for specific applications. Allowing colored options for printing not only decreases visual wear on prints and may allow for more applications, but it allows for creativity in certain projects. For example, if one is replacing a physical piece in a board game, one would want the replacement printed piece to match the old one as closely as possible - and colored filament can easily enable this. Certain applications also require different types of materials that are readily available in filament options. For example, if one is needing a part for the casing of a small motor, one would need a tougher plastic than PLA that could withstand not only the physical strain but the heat it would be subject to. A perfect material for this case would be PETG. It is mechanically stronger than PLA while also being more heat resistant. If someone wanted to 3D print a wheel, they could print with a flexible material such as TPU. All of these filaments are safe to use and breathe around too. Keeping various filament types on hand enables users to use whichever one suits them best. One can make the counter argument that switching filaments is wasteful as some filament will inevitably be left in the printing head, however, with the efficiency of current printers that is no longer the case, and only around 0.1 grams of filament is wasted per filament switch. And changing the settings between different filaments is as easy as pushing a button when slicing the model for print.

A current size limit of a 4" cube is placed on prints requested at the inVenTs Studio, which is reasonably assumed to limit print times and filament consumption to allow equitable access to every student in Galipatia. While understandable, this physical constraint severely limits several

use cases for 3D printing like part printing and prototyping. A better, more enabling limit, might be placed instead on the grammage of filament that a print requires. With a constraint on this parameter of prints, consumption and print times can be managed, and larger but less dense prints can be made. Moreover, modern slicing softwares and printers can relatively accurately predict the filament grammage that a print will consume.

In a student survey sent out to the Galipatia 21'-22' Discord, students were asked various questions on their thoughts about the current 3D printing service at the Studio. 91% of students wished they were able to choose the plastic type and color type of their prints. 91% of students also believed that the 4 inch cube was limiting in printing size. 100% of students believed that they would use the 3D printer more often if they were able to receive their prints faster. 63% of students also believed that their print should be available within three days. Evidently, there is a demand for faster print return times and more customization options, and thus there is a need for some level of improvement to be made.

At the end of the student survey, students were asked for any suggestions they might have. Two students mentioned how they would benefit from 3D printing file creation and printer operation training. This can easily be integrated into the current Studio Training Committee's umbrella, and is likely easily implementable with the frequency of engineering students already having knowledge in this area. Another suggestion was to upgrade to a larger printer that allowed an 8" cube print size. The Studio already has a printer capable of this size, it is just limited by the 4" limit in place, so there is a desire for larger prints.

A proposal to improve the Studio's 3D printing service

In order to create a proposal, its goals should be laid out at the beginning. The goals this proposal aims to effectively achieve are as follows.

1. Quick turnaround time ie < 3 business days from form completion
2. Practically automatic printing with very little user input
3. Ability to choose color/plastic type of print
4. Ability to have multi color prints
5. Ability to print larger objects
6. Ability to see status of your print
7. Ability for the users to see the average turnaround time of prints

To start, the 3D printers should all be standardized. They should all use the same size filament and the same slicer. Ideally, the same printer should be bought multiple times, that way a print can be sliced and used for any of the various different printers. Currently the Studio has an Ultimaker S5, Lulzbot Taz Workhorse and two uPrints. The uPrints should be sold off/removed as seemingly none of the GAs know how to use them, they are in the plan to remove already, and they take up a lot of space that could be used for other purposes. The Lulzbot, on the other hand, works inconsistently. With tweaks it could work well, but it uses its own proprietary slicing software making it frustrating to use. This printer should also be sold off/removed. The Ultimaker uses Cura as a slicer, which is compatible with most other printers, but it uses 2.85 mm filament which would make it incompatible with other filaments. However it should be kept because of its ease of use, its ability to print two materials/colors at once, and its 300mm by 300mm print bed. The Ultimaker should be kept for its use in the broader idea. Filament for the uPrint should be sold alongside the uPrints and the 2.85 mm filament should be kept for the Ultimaker.

To tackle the goals, replacement printers should be chosen. The top recommended picks are shown below. They are hobby/consumer printers, which may seem like a downside, but it makes them more easily repairable if they were to break down. They are also more affordable to purchase, allowing the purchase of more than one within a smaller budget, which would increase the output rate of prints. Buying one commercial printer could take up the budget of many consumer printers.

The first suggestion would be the Prusa Mini+. Historically Prusa is known to be the golden standard in terms of hobby 3D printers. Their reliability and consistency that they print out is unmatched, and are recommended by all sorts of 3D printing news outlets, including the New York Times [1]. The Prusa Mini+ features a 7"x7"x7" build volume, automatic bed leveling and multiple safety features. If the filament were to run out, or the power goes out, the printer will

pause itself and resume once the issue is resolved. It also runs with an easy to use slicer and has near silent operation. Prusa also supplies ready to use profiles where it is as simple to use as an Ultimaker. If any issue were to arise, there is a wealth of information available and 24/7 support from Prusa themselves. The price of the Prusa Mini+ is $379 [6] and comes as a kit, which would need to be assembled which is standard for hobby printers.

Another option to consider is the Prusa Mini+'s big brother, the MK3S+. It is just as reliable as the Mini+, but with a bigger build volume 9.84"×8.3"×8.3". It features a direct drive extruder which would make it easier to print flexible plastics such as TPU. It can also be upgraded to a multi material extruder, which would make for automatic printing with various colors. Newman Library's prototyping studio uses an older version of the MK3S+ and they are proven to be reliable workhorses [3]. Prusa themselves use 500 of them in their own automatic print farm [4], used to make more 3D printers. However, an inhibitor to the MK3S+ would be its price point at $749. The MK3S+ would also come in as a kit which would need to be assembled like the Mini+.

Regardless of the printer purchased, each of them should have their brass nozzles replaced with E3D's NozzleX. Brass nozzles are cheap starting nozzles that degrade overtime with the amount of printing hours they have on them, and will degrade further with abrasive filaments. The NozzleX is made from a special alloy of steel that has the heat conductivity of brass but with the hardness of steel. This is not completely necessary, but it will cut down on maintenance costs in the future.

Choosing a hobbyist 3D printer is essential due to its compatibility with OctoPrint. OctoPrint is a free software that can connect to the USB port on most 3D printers and it allows them to be controlled through a web server on the host device. Files can be sliced in Prusa Slicer and automatically uploaded to OctoPrint, from which the user can start the print from the computer, without ever touching the 3D printer, similar to the Ultimaker. OctoPrint has various helpful plugins which will enable the Studio to enact certain actions needed. However OctoPrint only works with one printer at a time. Thus in order to operate multiple printers, multiple instances of OctoPrint will be needed, which can be handled through Docker containers on a host computer.

Utilizing OctoPrint's plugins is essential to get the full functionality of the software. In this case, the Studio should aim to utilize the following: Filament Manager, Continuous Print, and the Spaghetti Detective.

Filament Manager is a basic plugin that allows the user to input their inventory of spools and select which one is being used when printing. This would be helpful in trying to keep track of the amount of filament being used and can be analyzed for the various popular colors students

may be using. Overall this would be a more efficient way of keeping track of the Studio's inventory when students are printing their files.

Continuous Print will be essential to automating printing overnight and unattended. It allows the user to queue sliced .gcode files and will automatically run after the last print. It will also remove the prior print by using the extruder head to knock the print off depending on height. The user can slice and upload many different files to OctoPrint, set up the queue and let the printer work. As long as the printer does not mess up during the print, all the files will be produced correctly.

The Spaghetti Detective acts as an insurance policy. Since the Studio would do more unattended printing, there is the possibility that it may mess up a print and end up with tons of wasted filament. The Spaghetti Detective utilizes a webcam and machine learning model that will detect a percentage of error and cancel the print in case there is any issue, minimizing filament waste.

Depending on how many printers the Studio will be utilizing, OctoPrint and its various plugins should be set up exactly the same. Every instance of OctoPrint should have a webcam setup in order to monitor the prints and utilize the Spaghetti Detective. With OctoPrint, everything would be extremely simple and easy to use.

So what would be the optimal setup? There should be two main printers along with the Ultimaker. In showcasing a full setup that would hit all of the goals, a Prusa MK3S+ with a multi material upgrade and a Mini+ would be purchased and used alongside the Ultimaker. If the Studio were to get two Mini+s, the setup would be nearly identical just without hitting the multi color goal.

The Prusa MK3S+ with a multi material upgrade should be used as the autonomous printer. The multi material upgrade can allow for up to five spools be used and ready to print with at a moments notice [7]. This would allow the user to set up 5 various colors in which the printer knows which one to pick for specific prints in the queue. For example, five students upload their prints, each wanting a different color. Student #1 wants their print red while student #2 wants their print green. Once the first red print is complete and removed from the print bed, the extruder will switch to the green filament and start printing with that at all the necessary settings in place. The autonomous printer should also be placed on an elevated surface. This will allow some sort of collection bin to be placed underneath, letting the previous prints be knocked into it and collected. And of course, the Spaghetti Detective would be actively running throughout the night and preventing any issues from wasting filament.

The Prusa Mini+ will act as a standby printer and an overnight printer. Due to its smaller build volume, it's more inclined to be used for smaller parts. Students working in the Studio who need

a quick 30 minute print done can ask a trained operator to put on their specific part. This would be helpful to students who regularly attend the Studio and would like to skip the 3 day wait for their part they need currently. It would also increase Studio attendance for students who need their print the same day. Thirty minutes prior to the Studio closing, the Prusa Mini+ should be set up for automatic use, where multiple prints of the same color are placed on a queue and set up similarly to the Prusa MK3S+. This way the print queue can be continually moved through.

The Ultimaker should be moved to large format 3D printing only. This will be an outlet for students to create larger 3D prints without having to worry about any limits. However, time is still an issue. The current Ultimaker has two print cores, one optimized for PLA and another optimized for soluble supports. The print core optimized for soluble supports should be kept, while the PLA one should be swapped out for a .8 nozzle AA print core. It is still optimized for PLA, but with the .8 nozzle it should be able to print much faster, albeit with less detail. But students printing larger objects should be aware that the detail won't be as good. The .8 AA print core would cost $115 [8].

Two types of filament should be purchased for the Ultimaker and the Prusas. Ultimakers can only use 2.85 mm filament while the Prusas can only use 1.75 mm. PolyMaker is a consistent brand that produces properly wounded spools with no tangles in a variety of materials and colors. Not to mention their spools are completely recyclable once finished. On average PLA and PETG cost $22 [9] for 1kg from them in a variety of colors. Their flexible plastics cost about $30 for 750g. The Studio should purchase about 3kg of white 2.85 filament from them and then a variety of 1kg 1.75 mm colors. The colors should be chosen based on a survey of the most popular colors used. The Studio should also purchase PETG and TPU in white at 1.75 mm in size. A filament dry box should also be purchased to rejuvenate old filament. The longer filament stays out, the more moisture gets into the filament, which causes issues with printing. For example, water soluble supports will not print if they have lots of moisture in it, essentially wasting the entire roll of filament. A filament dry box will take out all the moisture in your spool and make it as if it was brand new.

Due to there being essentially two different printing systems, it would make sense to establish two queues which vary on the printing system. The Prusas will act as the normal printing system and have a general size limit of 7"x7"x7" which is superseded by a grammage limit as previously mentioned. This grammage limit should be around 150 grams, which would be about $3.30 worth of filament (based on an average of $22 per 1000 grams of filament). However, each print would not cost $3.30 worth of filament. Typically students won't print a dense 7" cube, instead they would rather print a 7" tall bust with a 3"x4" base that may be about 50 grams. The point is, that a student would not typically reach the 150 gram budget. The Ultimaker should not have a size requirement, rather just relying on the printing operator's discretion. Prints, however, should not exceed 350 grams of filament, which would be about $7.70. This larger queue

would have longer wait times and would not allow the student to pick their plastic type nor color type, because typically students would just paint over their print anyway.

In order to establish this dual queue system, the form will begin with a question asking about size. Depending on their answer to size, the form will move them to the faster queue or the larger queue. At the top of each queue, it will inform the students of the rules in place, such as the size limit and grammage limit. Then the form will continue as it is now. In the connected Google Sheet to the form, each individual queue should be highlighted accordingly in order to show the printing operator which print needs to go where.

The final piece of the proposal is a 3D printer worker that handles all parts of the 3D printing service. This would help relieve the GAs' duties and would ensure that the printing queue has a constant stream of output. This worker would be in charge of maintaining the printers, maintaining the queue, approving files, and setting up the various automatic prints. If the 3D printing service is shown to be as reliable and flexible as this proposal expects it to be, it can quickly become its own subsection of the Studio that everyone can get their hands on. This worker would also be expected to come in every day that the Studio is open and place the finished prints into a box for collection. Once the print is in the collection box, the worker is responsible to notify the requester that their print is finished and ready to be picked up. This position should be only offered to established Studio users and hired through their knowledge on 3D printers. As compensation for working as the 3D printing operator, the student should receive the same compensation as a mentor per semester, if not more. Any student should be able to be hired as long as they are committed and knowledgeable to the printers.

Budget

A spreadsheet with the budget can be found at this link or on the following page.

https://tinyurl.com/56p98nck

It features three various setups, each with their respective notes at the top and then the common items beneath them. The totals for the various combinations can be found all the way to the right. The common items are split into a more general category along with an initial filament category. The initial filament category will act as a good starting point for the initial period. Any filament should be replenished as the spool is used up.

The overall cost of everything could be reduced due to the selling of other machines. For example, the amount of money made from selling the uPrints and the Workhorse could balance out the costs of new machines and hardware.

Item	Link	Notes	Price	Quantity	Total		Total Setup + Common	
Optimal Setup		Hits all the goals at a good price point					Optimal	$3,207.00
Prusa MK3S+	https://www.prus		$749.00	1	$749.00		Best	$3,886.00
MMU2S	https://www.prus		$299.00	1	$299.00		Sub Optimal	$2,528.00
Prusa Mini+	https://www.prus		$369.00	1	$369.00			
				Total:	$1,417.00			
Best Setup		Hits all the goals with both printers working as multi color autonomous printers						
Prusa MK3S+	https://www.prus		$749.00	2	$1,498.00			
MMU2S	https://www.prus		$299.00	2	$598.00			
				Total:	$2,096.00			
Sub Optimal Setup		Does not hit all the goals but achieves an autonomous printing queue						
Prusa Mini+	https://www.prus		$369.00	2	$738.00			
				Total:	$738.00			
Common Between Setups								
Ultimaker Print Core	https://shop3dun		$115.00	1	$115.00			
C270 Webcam	https://www.ama		$25.00	2	$50.00			
NozzleX .4 mm	https://www.ama		$35.00	2	$37.00			
Filament Dry Box	https://www.ama		$50.00	1	$51.00			
Computer		Any computer would work, don't spend more than $400	$400.00	1	$400.00			
Filament Budget		In case the Studio runs out of filament	$300.00	1	$300.00			
Misc Costs		Shipping, taxes etc	$200.00	1	$200.00			
				Total:	$1,153.00			
Inital Filaments								
Black PLA	https://www.ama		$20.00	2	$40.00			
White PLA	https://www.ama		$22.00	2	$44.00			
Red PLA	https://www.ama		$20.00	1	$20.00			
Blue PLA	https://www.ama		$20.00	1	$20.00			
Green PLA	https://www.ama		$22.00	1	$22.00			
Purple PLA	https://www.ama		$20.00	1	$20.00			
Yellow PLA	https://www.ama		$20.00	1	$20.00			
Orange PLA	https://www.ama		$20.00	1	$20.00			
White TPU	https://www.ama		$28.00	1	$28.00			
White PETG	https://www.ama		$22.00	1	$22.00			
White 2.85mm PLA	https://www.ama		$27.00	3	$81.00			
				Total:	$337.00			
Recurring Costs								
3D Printing Operator		Paid out per semester, similar to mentor	$300.00	1	$300.00			

Author's Note

Thank you for reading the proposal! I understand it was a lengthy read, but I hope you took in the suggestions and aim to utilize them. As someone who absolutely loves to 3D print, it was a bit sad to see the 3D printers not being utilized often and most of them just sitting around. You can create so many cool complex models from 3D printing that are not possible on a laser cutter or not as accessible to do on a CNC machine. It also saddened me to see that people were waiting seven days to receive a little 4" cubed max print. Back in the Fall semester, I was building a keyboard. Having already built a keyboard out of stacked wood and acrylic, I wanted to switch it up and do a 3D printed case. That 4" maximum turned me away from the Studio and pushed me towards Frith where they were able to print out all four pieces of my case, in a single day. I would love to make the inVenTs Studio on par with Frith and truly care about this makerspace. Bemnet, Emily and Esther all know me and know my passion for creating cool things, and having a proper 3D printing queue would just enable me and others to create fun and interesting things. I will even offer myself to be the trial student who can build and set up all the printers. I'd also set up the queue system and the autonomous functions of the 3D printers. I would even write detailed documentation ensuring any future 3D printing operator would understand the system and be able to make it work. I am seriously passionate about 3D printing and I hope you guys take the proposal into consideration. Feel free to ask me any questions at aviola@vt.edu or andrew@viola.dev, I would love to discuss other viable options if needed. An online version of this document can be found at: https://tinyurl.com/2ar84kec.

Sincerely,

Andrew Viola

Sources

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