DEMOCRATIC MANUFACTURING: A STUDENT MANUFACTURED & OPERATED 3D PRINTER FARM

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ABSTRACT
The DIY movement goes back to the late 60's and started the trend of shared tools as a reaction to the lack of skills and education on how things are made; this resulted in an increased awareness of democratic manufacturing resources and facilities, especially makerspaces and hackspaces, innovation labs, 3D printer farms etc. At Nottingham Trent University (NTU), we have observed an increase in students choosing to study Product Design thus increasing pressure on workshop/manufacturing spaces, especially automated manufacturing resources such as 3D Printers. Subsequently, the maker experiences students have been experiencing within the workshop environment temporarily lessened to ensure the needs of our rapidly increasing student cohorts are catered for. This paper explores how democratic technologies and manufacturing tools have overcome this issue by enabling designers, makers, and hobbyists to increase their access to facilities within the Product Design Department at NTU. This paper explores/reflects on the initial development of a 3D printer farm located in a product design studio where a group of sixty-nine students manufactured/assembled eighteen Creality CR-10S 3D printers. The success of the initial student led democratic manufacturing project resulted in ADBE developing a second 3D printer farm in a second product design studio consisting of a further eight Creality CR-10S V3 3D printers. The 3D printer farms are now complimented by a blended induction allowing for student independent use of the resource. Student feedback is also presented regarding the blended induction to ascertain knowledge acquisition and confidence on using the resources independently.

Keywords: 3D printing, blended learning inductions, democratic manufacturing, product design education, technology literacy

1 INTRODUCTION
As a reaction to the increased capacity issues, demand for teaching and learning on modern manufacturing methods and student enthusiasm to learn about modern manufacturing methods, the democratic manufacturing project within The School of Architecture Design and Built Environment (ADBE) at Nottingham Trent University was created. This paper focuses on a student manufactured, operated, and maintained 3D printer farm. Within ADBE, the aspiration is to constantly improve facilities and student engagement with hands on experience, especially in workshops and studio spaces, which in recent years has been limited due to capacity/footprint restrictions, cohort sizes, national lockdowns etc. The democratic manufacturing project focused on providing students the opportunity to assemble/manufacture, operate and maintain a 3D printer farm within their product design studio.
A 3D printer farm is a large collection of 3D printers situated in one location; an example is the Monkeyfab Prime 3D printers shelved in one location at The Department of Automotive and Machine Tools at the Warsaw University of Technology [1]. 3D printer farms can be framed in two contexts i.e., integrated production, and consumer production. Integrated production 3D printer farms provide the possibility of dramatically influencing the supply chain through automation [2]. 3D printer farms also offer automated manufacturing possibilities i.e., Prusa Pro AFS Automated Farm System [3]. 3D printer libraries have been trialled, providing a point of access/support for 3D printing for students/faculty across disciplines beyond engineering and technology [4]. There are many benefits of using 3D printing in engineering education, offering learning opportunities across computer aided design (CAD), digital manufacturing, software skills, amongst others [5]. 3D printing is used in various teaching settings

ranging from schools through to higher education and across multiple subjects ranging from engineering, product design, amongst others [6]. 3D printing used in combination with eLearning tools for design education offers many opportunities; eMaking can help bring together the virtual and the physical worlds in the design studio [7]. There are many learning challenges within product design that encompass physical/digital making; bridging the learning gap from the studio environment to labs or digital manufacturing laboratories is essential to embed learning through technology use whilst still being considerate of critical making [8]. This extends beyond typical design studios, fabrication laboratories or makerspaces; 3D printing services are offered in academic library environments too [9]. This paper explores/reflects on the initial development of a 3D printer farm located in one of the product design studios at NTU where a group of sixty-nine students manufactured/assembled eighteen Creality CR-10S 3D printers completing a four-week 3D printing project. The success of the initial student led democratic manufacturing project has seen ADBE invest further and develop a second 3D printer farm in a second product design studio consisting of a further eight Creality CR-10S V3 3D printers. Both 3D printing farms are now 100% student operated, accessible seven days a week, with no staff supervision required. Students require a one hour thirty-minute blended learning 3D Printer farm induction developed to give students a quick hands-on learning experience that enables them to gain confidence in using the 3D printers when inducting themselves. This step-by-step induction resource allows students to follow along learning how to use the 3D printers and the supporting software. Feedback on the induction process has been collected, demonstrating the successes of the project. Overall, over the past two academic years, over 300 students have self-inducted themselves into the 3D printing farms resulting in a dramatic increase in awareness of democratic manufacturing resources.

2 BUILDING THE 3D PRINTER FARM

The initial democratic manufacturing project was set to a group of sixty-seven BSc (Hons) Product Design first year students in the 2019/20 academic year. Students selected their pairings which were later collated into groups of four/five. Each student group was provided with a DIY kit for a Creality CR-10S 3D printer and were tasked to construct, calibrate, and produce test prints together (Figure 1). Each student group was provided with a set of simple instructions and a standard user manual provided with the printers to aid the initial constructions and assembly. Students could however use additional video tutorials and content available online or seek support from the tutors. The students were also tasked with documenting their construction process as part of the project, they were expected to produce a more detailed and informative user manual which could be shared with future student groups who would learn how operate the 3D printers when fully installed and located in the 3D printer farm location.

Figure 1. BSc Product Design Year 1 Students Building Creality CR-10S 3D Printers

Alongside the construction of the 3D printers, the students were tasked with designing a board game within their groups, all components beyond the board game boards had to be 3D printed (Figure 2). This forced each student to interact with the 3D printers and produce accurate components on a small scale. Students were also aware that between the sixty-seven of them, there were only eighteen 3D printers, therefore they were required to work in a democratic manner by sharing resources. Feedback from students highlighted the positive impact of the initial democratic manufacturing project with students suggesting that they enjoyed the hands-on approach to building a machine and then utilizing this machine in practice to produce usable components. Feedback collected identified that for many students this was their first experience being hands on with manufacturing technologies not ordinarily accessible to them. The construction/assembly of the 3D printers also gave them a sense of ownership and pride in not only utilizing the resource but maintaining it too:

> *"I like how the module got more hands on (i.e., the construction of the 3D printers) this allowed us to utilize our skills learned from other sessions (i.e., Solidworks 3D CAD sessions). It feels like I am practicing and comprehending my skills and knowledge together. I also like that the 3D printing lectures provide up to date industry knowledge". [Anonymous]*

> *"I liked how creative I had to get… I have enjoyed research about new and interesting concepts. Learning how to independently 3D print anyway was the aspect of the teaching I valued the most". [Anonymous]*

Figure 2. Board Games & 3D Printed Components – Credit: B.Green, B.Holmes & D.Kapoor

Following the success of the initial democratic manufacturing project and the rapid increase in demand for 3D printing across the product design cohorts, but also the sudden change to working practices due to COVID-19 social distancing, this resulted in two priorities being identified. Firstly, a second smaller 3D printing farm for a second product design studio to help facilitate other product design cohorts democratic and digital manufacturing needs was required. Secondly there was also a need for an induction process to be created that could be delivered in a blended teaching and learning environment, whilst being socially distanced, thus helping to reduce the reliance on one-to-one staff demonstrations.

3 DEVELOPING THE BLENDED LEARNING 3D PRINTER INDUCTION

With the dramatic increase in demand for 3D printing, it was decided that a one hour thirty-minute blended learning 3D Printer farm induction was necessary to allow individuals to induct themselves onto the 3D printers through the demonstration of the successful printing of a small component. The induction requires the students to gain a fundamental understanding on how to operate the 3D printers whilst also demonstrating successful manual leveling of the build plate, successful loading of material, appropriate setup of files within a slicer program (in most cases this was Ultimaker Cura or Creality 1.2.3 slicer) and successful 3D printing of a sample part. To conform to NTU's teaching and learning principles, we aim to offer videos in several segments each of which are no longer than ten minutes in length. A step-by-step induction resource developed (Figures 3 & 4) allows students to follow along learning how to use the 3D printers and the supporting software via a VLE learning room setup for 3D printer inductions.

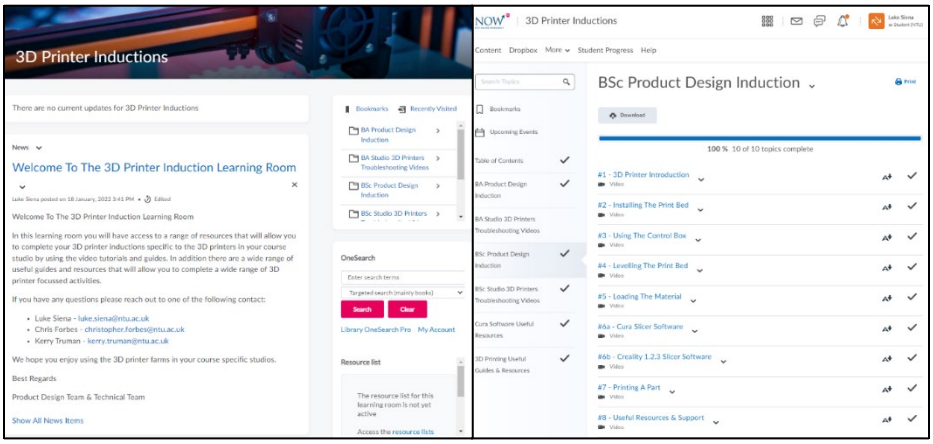

Figure 3. 3D Printer Inductions NOW Learning Room

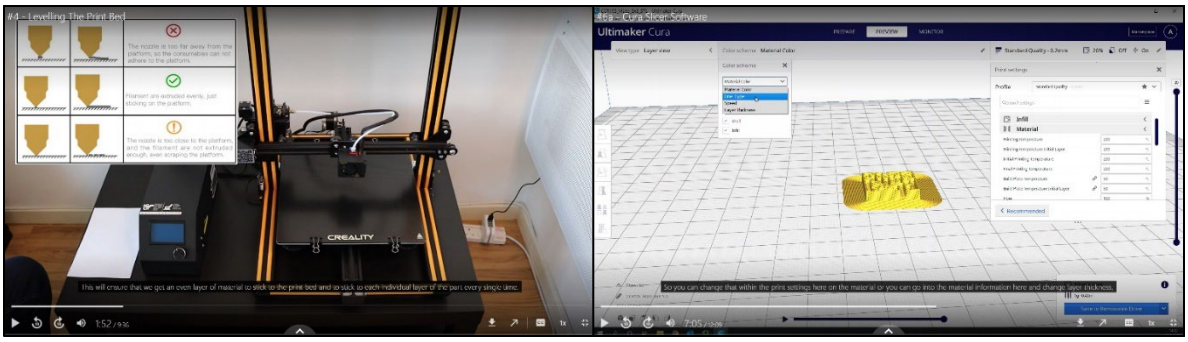

Figure 4. Video Resources Recorded to Support The Blended 3D Printer Farm Induction

We identified that the students needed to learn several new skills whilst understanding new software and terminology. We therefore aimed to make the learning experience quick and hands-on, enabling students to gain confidence in using the 3D printers and induct themselves into the facilities. It was necessary for the students to have a recourse to refer to at any time, as the demands of different courses would dictate frequency of access required. Students who used the 3D printers less frequently could therefore recap any knowledge forgotten after a period of none use. Eight videos were necessary to complete the induction, these covered topics including, a general 3D printing introduction, an overview on how to install/change a print bed, how to operate the control box safely, how to level the printer bed, how to load/unload material, how to operate a compatible slicer software depending on the device being used, how to print a part and finally how to access additional useful resources and support.

Due to the diverse range of students with varying needs, especially students with physical disabilities (e.g., hearing loss) or specific learning difficulties (SpLD's), several key principles were adhered to for accessibility compliance. Content was methodically delivered at a pace which allowed students with information processing conditions the time needed to digest/apply the information. All videos have fully embedded captions and are accessible on all devices. The videos are hosted on NTU's NOW (Nottingham Online Workspace) VLE and delivered via Panopto. This ensures all students, irrespective of their financial status and IT literacy can complete the induction regardless of the device used.

To facilitate the clarity of information, all videos were video edited in Adobe Premiere Pro to allow information to be overlayed/embedded (Figure 4) where simple video shots were not sufficient in communicating the desired information by themselves. To support knowledge acquisition on 3D printing, a series of 3D printing lectures and activities have been produced to support design for manufacture and assembly (DFMA). These videos explore Ultimaker Cura's features and provide detailed insights into how to produce functional components. Each 3D printer farm also has a material bank available to the students. Each 3D printer has been given an individual name to allow for easy reporting of faults to the relevant technical personnel. QR code posters are also placed in each 3D printing farm space to help students navigate to online resources. The QR codes also directly link to the 3D printer induction booking system that links to academic's calendars regarding availability.

4 LEARNER PERSPECTIVES & REFLECTIONS

Over the past twelve months, feedback has been collected from forty-nine students across BA (Hons) Product Design and BSc (Hons) Product Design courses whereby they completed an anonymous online survey so insight could be gained on the blended inductions. Eighteen participants were "not at all familiar" with 3D printing compared to thirteen that were "slightly familiar", twelve that were "moderately familiar", four that were "very familiar" and two that were "extremely familiar". Twenty-two participants found the induction videos "extremely useful", twenty-four found the videos "very useful", one participant found the videos "moderately useful" and two found the videos "slightly useful". Significantly, forty-seven of the participants found the members of staff supporting the blended inductions "very helpful" with two participants finding the members of staff "somewhat helpful".

After completing the blended induction, fifteen students were "extremely confident" using the 3D printers, with twenty-seven "quite confident" and seven participants "somewhat confident"; no participants identified that they were "not confident at all". In summary, across the forty-nine students who completed the survey, the average rating for the blended induction was 4.8/5.0 for their overall cumulative experience. From the open-ended questions provided for further comments, students provided further feedback with the below quotes demonstrating the positive experiences encountered:

"Methodical videos which were clear in breaking down the use steps. This allowed me to easily play the videos in parallel to using the 3D printers. Didn't feel overloaded with information". (P3)

"The step-by-step videos (were most useful) because they allowed everyone to go at their own pace depending on their personal familiarity with 3D printers". (P31)

(useful aspects included) "gaining basic understanding of how to use 3D printers, how to set up 3D printers and just being able to see one working in action". (P46)

Some of the student feedback that suggested areas for improvement focused on areas such as the online booking system for the inductions, the frequency and time-period of the automated reminder emails from the booking system not being frequent enough and also identifying challenges some of them faced during the induction when things went wrong; requests for more visuals or supporting videos were made:

"It would have been useful to know the day before that we needed laptop as not everyone checks there emails daily (to check the booking system reminders)" (P5)

(The videos) "didn't really mention what to do if something goes wrong with your print, and how to fix it". (P9)

"I found it challenging to set up the correct height (when levelling the print bed) for the base, as using the paper technique to see if there is friction isn't the most accurate" (P15).

Following feedback, additional useful resources and helpful hints videos have been recorded for each type of 3D printer. These focus on the unloading/changing of material, Z-Axis adjustment to allow for improved material loading/unloading, as well as supporting videos on more complex design considerations related to DFMA for 3D printing for functional prototypes. Student feedback included:

"Perhaps making students aware of common pitfalls that they can encounter when 3d printing in general" (P3).

"There wasn't a video for the unloading of material from the printer, this could be useful for those who don't have the background knowledge." (P42)

The 3D printer induction learning room on the VLE environment and provision of 3D printing resources has had a significant impact on student education over the past twelve months with over 200+ unique users engaging with the online induction resources. When considering NTU's success for all agenda, the 3D printer farm and material hub has provided all students with equal opportunities to learn about democratic manufacturing tools without having to worry about the associated costs to them:

Having access to materials and resources we need is also very helpful allowing me to get on with projects without having to worry about trying to find materials suitable for the machines such as the 3D printers. [Anonymous]

5 CONCLUSIONS

The development of the 3D printer farms at NTU has seen a dramatic increase in student DFMA proficiency within design projects. More notably, student confidence with democratic manufacturing machines/tools is at an all-time high, with students at key times during the academic year manufacturing models utilizing the 3D printers for $1^{st}/2^{nd}$ year project work in addition to the production of working prototypes for final year commercial and self-directed projects. The overall workflow for 3D printing has been drastically improved, with the student experience significantly improving (Figure 5). The rapid increase in digital manufacturing tools within the portfolio of product design courses at NTU continues to add value to the student experience. We are now exploring methods of increasing democratic manufacturing opportunities in the form of "Pop Up Workshop" initiatives which can be supported by a blended learning induction. These inductions can provide students with relevant health and safety knowledge, but also the confidence to utilize democratic manufacturing resources in the product design studios. We are also looking to expand the use of the blended learning inductions to cover other digital design and manufacturing resources, especially for other types of 3D printing/3D scanning.

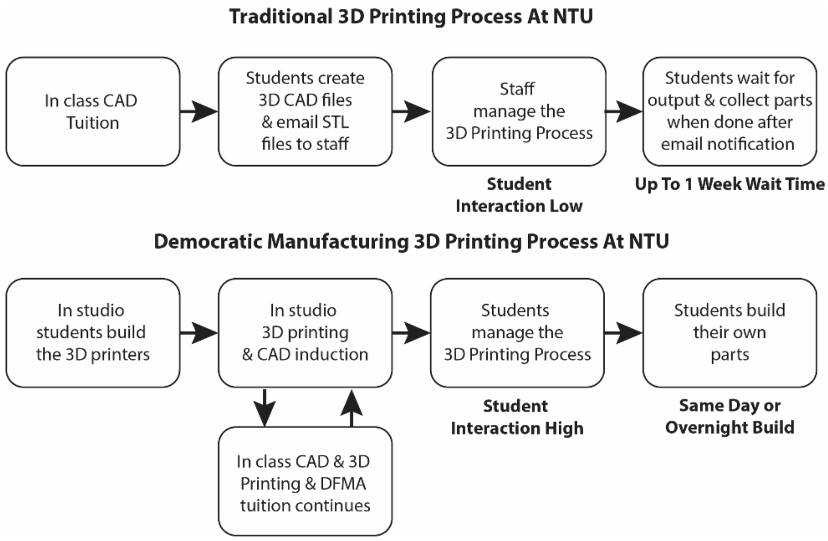

Figure 5. Comparison of 3D Printing Workflows

Due to student confidence with democratic manufacturing resources, especially the 3D printer farms, NTU is looking to expand the technical expertise retained by employing 1st year students as bank staff to help maintain the 3D printer farms. We are looking to train/deploy students into other areas of the workshops/studios especially as student numbers continue to grow whilst expanding the 3D printing farms by offering other low-cost machines with varied capabilities. As the online resources/inductions have proven popular and reduced the reliance on the technical specialists at NTU, we are looking to expand the online induction resource pool by offering bite sized videos on key topics. Although segmented, all videos are typically below 10 minutes in length, allowing students to access key resources quickly and get direct answers to queries. As we continue to expand our resources, the use of digital manufacturing for other hardware such as 3D scanners, virtual reality headsets etc., will aim to also improve the digital design workflow for our students and improve their technical proficiency thus having a positive impact on their employability in the years to come. The use of digital workflow systems such as booking systems for the blended inductions has also allowed for improved effective planning and delivery. Although challenging to setup, the student facing interface is straightforward for students to use/book their inductions. Due to our international/diverse student pool, initial interactions with democratic manufacturing tools and workshops experiences must be embedded in the students first year of study to give them the autonomy and confidence to become skilled product designers and industrialist.

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