

# 3D PRINTING IN MEDICAL APPLICATION: AN EDUCATIONAL DESIGN PERSPECTIVE

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## ABSTRACT

Medical applications for 3D printing are expanding rapidly and this technology is expected to revolutionize health care. The application of 3D printing in medicine and healthcare can provide several benefits including: the customization and personalization of medical products, drugs, and equipment. Normally, one have to either draw an object in a CAD program, download or optimize a digital model that is generated by Magnetic resonance imaging (MRI), ultrasound imaging (US), 3D scanning, or computer tomography (CT) to a 3D printing process. Although 3D printers could be regarded as an engineering and designer's tool, a broader aspect of the technology and its effects on motivation for the students, in particular for medical applications, has not been reviewed previously. One would question the level of integrating such a device into engineering student curriculum, and how would that gain the level of students' knowledge to make faster prototypes and examine ideas in a faster pace.

In this paper, different cases with medical applications using 3D printers are elaborated, and the barriers and controversies of 3D printing and its related processes in light of two medical applications in addition to its educational effects are discussed. A workflow that can be considered for processing any medical applications with 3D printing is also suggested. Shortly, our experiences with the students are elaborated on achievements of their goal through a systematic process by using 3D printers in medical applications.

*Keywords: Medical application, 3D printing workflow, motivation, engineering students.*

## 1 INTRODUCTION

Additive manufacturing is defined as a process of joining materials to make objects from a 3D model, usually layers upon layers, as opposed to subtractive manufacturing methodologies as milling, casting or a combination [1]. A 3D printer is a machine that uses concept of additive manufacturing for 3D printing. One would often hear of desktop 3D printing being a tool for designers and engineers, but prototyping technology is also an important tool in healthcare, especially for medical and dental devices, in addition to modelling and surgical planning purposes. Some even believe that the 3D printing will be partially responsible for a situation in which "more than a third of the desired core skill sets of most occupations will be comprised of skills that are not yet considered crucial to the job today (future jobs).

The applications using 3D printing in medicine can provide many benefits, including the customization and personalization of medical products, drugs, and equipment. Normally, one have to either draw an object in a CAD program, download a similar model from the internet as Thingivers.com, or optimize a medical image that is generated by Magnetic Resonance imaging (MRI), ultrasound imaging (US) or computer tomography (CT) to a 3D printing process.

Based on the demand for the future jobs [2], it would seem that the education system has an opportunity and an incentive to consider 3D printing as a priority in their program. Based on the work of Dewey, in the early 1990s, Seymour Papert developed the educational theory known as constructionism, which advocates for teaching both in context and with an understanding of a student's motivation for learning. Papert's idea of experiential learning is the motivating force behind

one effort promoting 3D printers. As a rapid prototyping process, it is much easier to motivate the students to make models or parts of a device with 3D printing rather than traditional manufacturing methods.

In this paper, a special workflow design is suggested to systemize the way to work with project that involve 3D printing of medical related applications specially engineering students. Two medical device projects involving 3D printers are presented as examples of the way the workflow was applied.

## 2 3D PRINTER AS A FABRICATION TOOL

The 3D design and fabrications' tools have traditionally targeted professionals or technically inclined users for some time. In the early days, the cost of printing was expensive and so the consumer market and interested industries were limited. With drastic technological developments for the past decades, the cost has drastically decreased and has become increasingly available for the general market. Printers that used to cost more than \$20,000 USD in 2010 can now be found for less than \$1,000 [3,4]. Thus, the research on facilitating end user interaction with digital fabrication has grown recently [5]. The 3D printers are used to manufacture a variety of medical devices, including those with complex geometry or features that match a patient's unique anatomy. Some devices are printed from a standard design to make multiple identical copies of the same device. Other devices, called patient-matched or patient-specific devices, are created from a specific patient's imaging data. Commercially available 3D printed medical devices include:

- 1) Instrumentation (e.g., guides to assist with proper surgical placement of a device),
- 2) Surgical implants (e.g., cranial plates, hip joints, or odontological implants)
- 3) External prostheses (e.g., hands).

Scientists are researching how to use the 3D printing process to manufacture living organs such as a heart, liver or muscle, but this research is in early stages of development and will not be further discussed in this paper.

## 3 3D PRINTING WORKFLOW

Based on suggested steps by makers on the web, and mostly inspired by Hudson et al [5] and our own observations, a 7-steps model was synthesized from a typical workflow with 3D printing into a special workflow for medical applications (Figure 1).

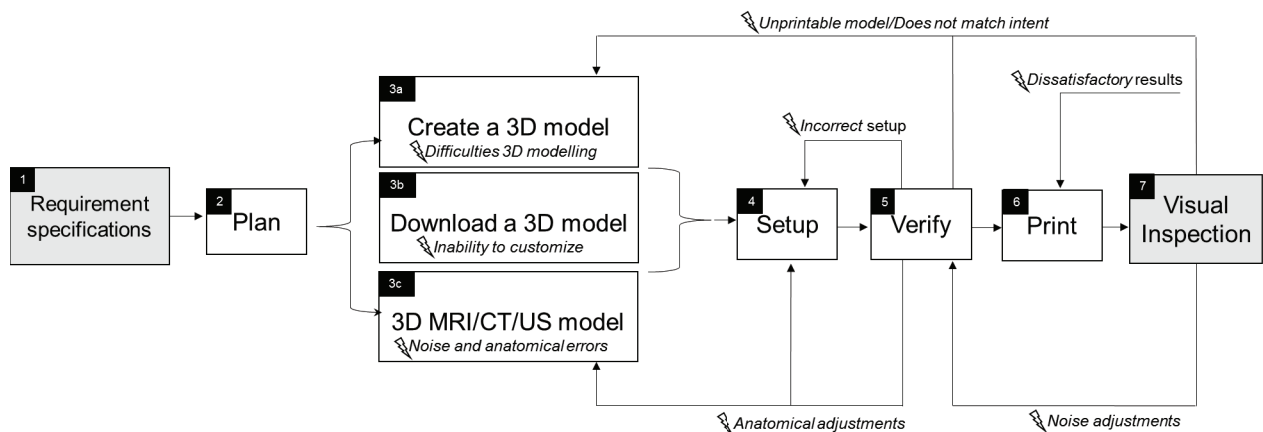


Figure 1. Making a 3D model passes through several steps a suggested workflow

### 3.1 Requirement specifications

As part of the project, students used a system engineering approach by using a V-model for process development [6]. Model is decided based on CONOPS (concept of operations) and is mostly used to identify the potential interests and requirements to make the project successful. In general, a medical device must first pass a set of standards and regulations designated by its classifications [7]. Devices are classified as Class I, II, or III based on risk of the device, and the level of control necessary to assure safety and efficacy. Class I devices are considered low-risk and are subjected to general controls alone, while Class III devices, which includes mostly implants, are considered high-risk and

are subjected to the most complete and stringent standards. Most devices that our students have produced are classified as Class I. Furthermore, the requirements specification contain specific information about the dimensions and tolerances of the object to be 3D printed in addition to the required material properties such as force tolerances, colours and surface roughness. Based on the information it is possible to choose what type of 3D printing technology should be applied.

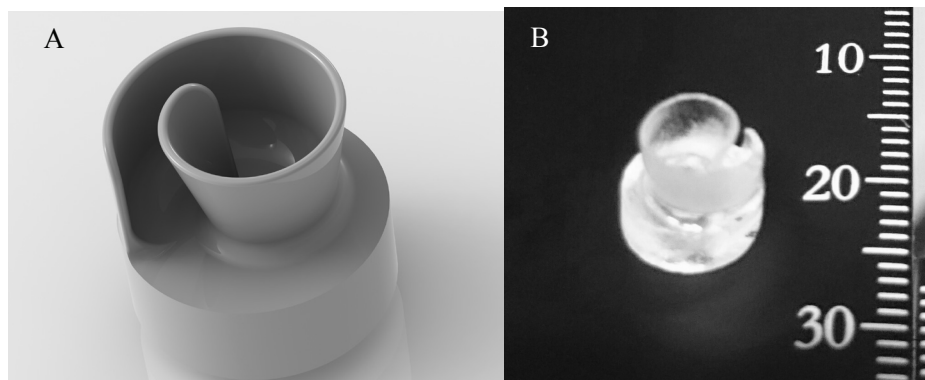
### 3.2 Planning

When the requirements specification is completed, the students should have a clear idea of details of the devices. Since the students may think that they cannot map all steps that is needed to succeed, the planning phase is usually demotivating for some students. Thus, a close advisement is suggested to reassure the students about the process and explain how important this step is for the outcome of the process and the results. At this step, the students have chosen the selected 3D printer that can satisfy the needs to solve the solution, and they are ready to choose one of the possibilities in next step.

### 3.3 Digital Model

#### 3.3.1 Create a 3D model

Most students at our department create their own 3D models by using a single modelling tool for all kinds of models. Popular 3D modelling tools are Sketchup, 123D design, OpenSCAD, Solidworks, Autodesk Inventor, and Blender. A 3D digitization-modelling course, using the program Inventor, is available at our Department, and therefore almost 90% of about 30 students at our lab have chosen Inventor rather other possibilities. However, a few others have used Sketchup (3%), openSCAD (2%) and Blender (5%) to create their own model. The argument for using other programs is due to the fact that they are open source, free of charge and accessible, and were mostly applied at personal computers at home rather than the departments' computers. The advantage of being expert/familiar with this 3D program speeds up the modelling process of the objects and gives a feeling of mastering which is very motivating for students. However, the students do not gain any additional knowledge about the coding of open source programs as OpenSCAD or Blender. As an example of 3D digitization- modelling , a pump impeller was designed with critical dimensions inside a medical catheter with a diameter of 11 mm. Figure 2 shows the 3D digitized model, and the 3D printed prototype with a transparent material with SLA Formlabs printer.



*Figure 2. Illustrates a self created part in the Autodesk Inventor (A), and its 3D printed physical model using SLA technology from Formlabs with transparent material (B)*

#### 3.3.2 Download a 3D model

As an alternative to creating a 3D model, students can download a premade 3D model from a website such as Thingiverse. Thingiverse is a platform for sharing user contributed 3D models designed for 3D printing. On this site, members upload 3D model files (typically STL files), which can then be downloaded by other users of the site. According to the ASTM standard terminologies, the STL (STereoLithography) file format is a format commonly used for 3D printing, and describes a 3D surface built up of triangles [1]. This step is popular among students who were frustrated by the difficulty of using 3D modelling tools, or those who wanted to test the 3D printing machines for their quality. This process has been regarded as a motivating tool for students as they could get some idea of how the device is functioning and how to manipulate it to their own advantages. Another example

of an impeller in used a heart pump was tested by students with an already designed wind spiral that was found on Thingivers. The object was only scaled and 3D printed with the transparent material with a Formlabs 3D printer (see figure 3).

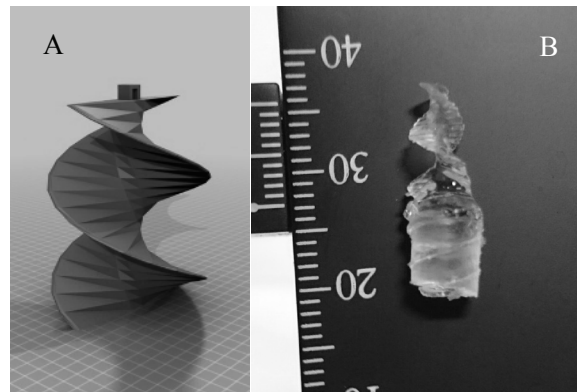


Figure 3. Showing A) an example of a downloaded 3D model from Thingivers.com and B) the result of the printed part with SLA printer from Formlabs with transparent material.

### 3.3.3 Making a 3D model based on MR/US/CT modalities

A Digital Imaging and Communications in Medicine imaging (DICOM) is a standard for handling, storing, printing, and transmitting information in medical imaging. Making a 3D model based on any imaging modality as magnetic resonance imaging (MR), 3D scanning, ultrasound imaging (US) or computer tomographical imaging techniques (CT) has to involve a conversion of DICOM based files into STL format. Such a conversion of formats, will usually introduce challenges as noise and deformations to the model. Although, the noise may be caused by the file conversion, it may be originated by the anatomical differences as well as the noise from the equipment. Thus is it important that the students making such models are familiar with both anatomical properties but also disadvantageous introduced by the applied imaging techniques. As an example, a micro CT image of the maxilla tooth had to be converted from DICOM file formats to a STL format. Figure 4. illustrates the DICOM file with a digitized STL converted file, and two different results from a SLA based printer from Formlabs (transparent colour) and a FDS MakerBot printer (white colour). There are no easy way to transfer the DICOM files into printable STL formats, and this step is not only time consuming but also has a lot of frustrations upon the students. Even though the students are familiar with the process, there are always the question of how each piece of the model fits anatomically with the rest of the 3D image and how the final result will look like when the printing process is finished

### 3.4 Set up the printer

When the model is satisfactory, it should be prepared for printing. Most 3D printers have a user guide explaining the preparation process step by step. They typically include a description of specific printer variables one can adjust, and also how to use a slicer program that slices the model into multiple layers for printing. At this step, the students adjust applicable variables like the layer height, infill density, print speed, material type, type of support material, and temperature. The slicing is done automatically by the program, and will transform the STL file to another format called G-code. This is a language that tells digital fabrication tools how to make the physical model. It is possible to tweak this automated process with enough coding experience, but this is very time consuming process and an automatic process is usually preferred.

### 3.5 Verify the model

At this step, the model is sliced and ready to be printed. Through an onscreen inspection, the students should have evaluated whether the design is likely to print properly and whether the printer's settings are correct. As a result, the students may have had to adjust their design or print settings. In case of any abnormal dimensions or noises introduced to the model independent of printer settings, the students should go back to the selected model and inspect the problems introduced to the models in step 3.

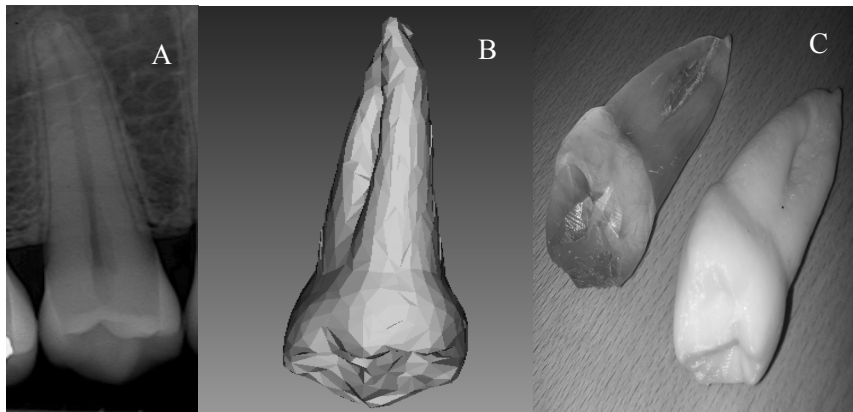


Figure 4. Showing A) an example of a micro CT (computer tomography) image of human tooth with B) a digitized model and C) 3D printing models using SLA by Formlabs printer (transparent) and FDS by Maker Boot (white). The length of the tooth is about 20mm

### 3.6 Print the model

After the validation step and resulting changes, students can finally print their model. At our lab, two different technologies have been mainly applied. They are fused deposition modelling printers (FDM) that uses thermoplastic parts which deposited layer by layer. In addition to the stereolithography apparatus (SLA) that is making objects by photopolymerization process using laser to cure the material into predetermined thickness and harden the material into shape layer upon layer. Both processes can normally be time consuming, and take from several minutes to hours depending on the physical size of the model. Normally, the FDM is much faster but with rougher surfaces as the result. The design is also not water tight, and water can be absorbed into the pores of the printed result. Although the previous steps have been done carefully, there is still a chance of dissatisfactory results. Small changes as humidity, room temperature, level and stability of the table that the printer is resting on, can contribute to influence the physical 3D printed model. Therefore, students have to run this process several times to get a satisfactory result which may sometimes be demotivating. It could also be stressful for students as the material to some of these printers are quite expensive.

### 3.7 Visual inspection of the physical 3D printed model

In addition to problems introduced by the printer, any issues that are not caught by the verification step could result in a failed printing step. A visual inspection of the printed model may reveal those errors especially when the students compare digital designed model with the printed model. If the 3D printed design failed or did not match the design intent, the students would have to adjust either their model or the print settings to correct the issue. Often this process have to be with the assistance of the laboratory engineers or more experienced students. This step is usually very frustrating for the students particularly because there may be several parameters that influence the process simultaneously which may confuse the students. A systematically troubleshooting through all the steps may solve any failure.

## 4 DISCUSSIONS

There is no doubt that 3D printing and modelling is receiving an increased attention in the education environment, in particular by engineering students specializing in medical devices and applications. Several case studies have investigated experiences installing 3D printers in public and university libraries [12,13]. These cases provide some insight into how these print centres were set up, but do not provide detailed insights into the workflows and barriers of students independently trying to fabricate digital objects using the tools provided by these centres.

The students were motivated to produce their desired objects, whether those objects were practical or novel in nature. For most of our students, additive technology in particular SLA technology was merely a means to achieve a goal. Hudson et al. 2016 also confirms the same as our observation [5]. There are several studies documenting experiences implementing and teaching 3D printing in academic environments. Some have explored the educational potential of making in a formal learning environment [8,9,10], finding that it provided students with hands-on experience and increased student motivation, performance and information retention. Additionally, Buehler et al. [11] studied the use of



3D printing and modelling in special education classrooms, and found that even with novice-oriented tools, students struggled to create their own designs. Our own experiences confirm the results of Buehler et al (op.cit.) but also shed light on other challenges with medical 3D printing where the knowledge of anatomy is also important. Although some of our students are familiar with 3D modelling in addition to anatomy and physiology through courses that are delivered at our department, this knowledge cannot help them to meet the challenges of combining two fields. Often it may act as a demotivating factor for the students. The challenges mostly play a major role when the design has to meet complex requirement specifications in medical applications. The suggested work flow is specially designed to meet those challenges.

## 5 CONCLUSION

Using 3D printers especially for medical applications is a challenging task as it involves additional knowledge about anatomy and expected biological shapes. In this paper, the significant challenges that may occur in a systematized workflow are elaborated with some examples. The goal of introducing such a technology more in the curriculum for engineering students is still remains to be answered. The current workflow and the experiences presented in this paper, may be an opportunity to encourage the students to complete their projects that involves prototyping.

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