Design and innovation with problem based learning methods: an engineering perspective

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3D PRINTING IN MEDICAL APPLICATION: AN EDUCATIONAL DESIGN PERSPECTIVE

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ABSTRACT

Medical applications for 3D printing are expanding rapidly and are expected to revolutionize health care. The application of 3D printing in medicine and healthcare can provide many benefits, including the customization and personalization of medical products, drugs, and equipment; cost-effectiveness; increased productivity; the democratization of design and manufacturing; and enhanced collaboration. 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 such a technology could be regarded as an engineering tool, a broader aspect of the technology and its effects on motivation for the students in particular for medical application 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, we are in particular elaborating different cases for applications using such a technology, and discuss the barriers and controversies of 3D printing and its related processes in light of two medical applications in addition to its educational effects. We present a workflow that can be considered for processing any medical applications with 3D printing. Furthermore, we elaborate the experiences with our students on how they achieved their goal through a rather creative process by using 3D printers for making medical device prototypes.

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

1 INTRODUCTION

3D printing is a unique technology and it has been referred to as additive technology due its additive manufacturing technique compared to other methods as milling, casting or a combination. We often hear of desktop 3D printing being a tool for designers and engineers, but prototyping technology is also making progress? in healthcare, especially for medical and dental devices, modeling 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 application of 3D printing in medicine can provide many benefits, including the customization and personalization of medical products, drugs, and equipment; cost-effectiveness; increased productivity; the democratization of design and manufacturing; and enhanced collaboration. 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 [1], it would seem that the education system has an opportunity and an incentive to make 3D printing as a priority in their program. Building 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. We experience that 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 milling and casting methods.

In this paper, we have suggested a workflow design which may systemize the way to work with project that involve 3D printing of medical related applications specially engineering students. We present two projects as an examples of how the workflow was adapted by our students at their final project before they receive their bachelor of engineering degree.

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 & interested industries were limited. With developments in technology, 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 [2,3]. Thus, research on facilitating end user interaction with digital fabrication and making has recently been growing [4]. The 3D printers areused 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 odonatological 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, inspired by Hudson et al [4], and our own observations, we synthesized a 7-steps model for a typical workflow with 3D printing (Figure 1).

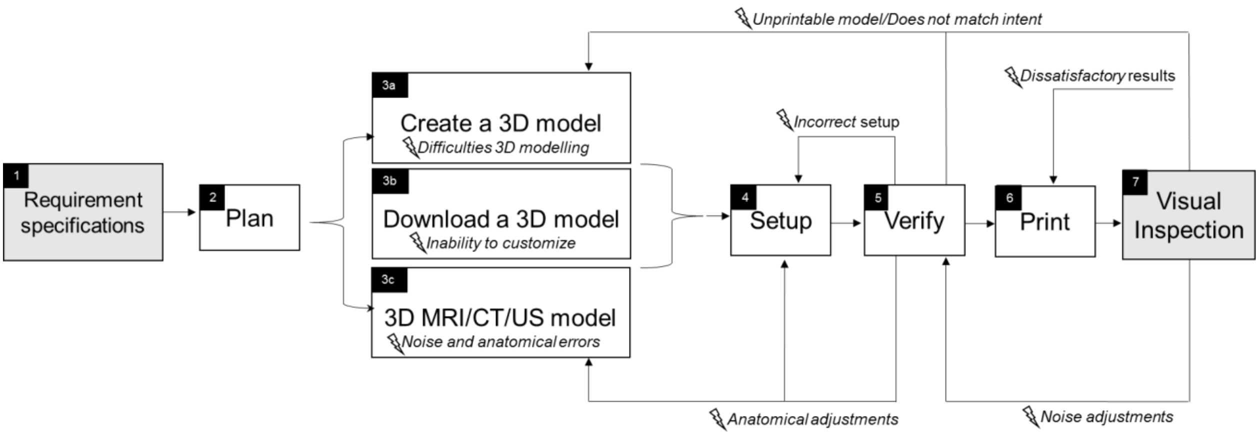

Figure 1. Making a 3D model passes through several steps a suggested workflow.

3.1 Requirement specifications

As part of the project, students use a system engineering approach by using a V-model for process development [5]. 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 class [6]. 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, colors and surface roughness. Based on the information it is possible to choose what type of 3D printing technology should be applied.

3.2 Planning

Based on the information from the requirements specification, the students should have an clear idea of what they want to create. Since the students feel that they cannot map all steps that is needed to succeed, the planning phase would be really 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 technology 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

2.6.1: Create a 3D model

Most students at our department create their own 3D models by using a single modeling tool for all kinds of models. Popular 3D modeling tools are Sketchup, 123D design, OpenSCAD, Solidworks, Autodesk Inventor, and Blender. A 3D digitization modeling 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. We experience that students using the aforementioned programs that are open source or free, were mostly applied at personal computers at home rather than the departments' computers. As an example, an impeller has to be designed with critical dimensions inside a catheter with a diameter of 11 mm. Figure 2 shown an image of the 3D model and its realized 3D printed part with transparent material with a Formlabs printer.We have no doubt that our courses in Inventor have influenced the choices the students have taken with regards to modeling tool program. The advantage of being expert/familiar with this 3D program speeds up the modeling 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.

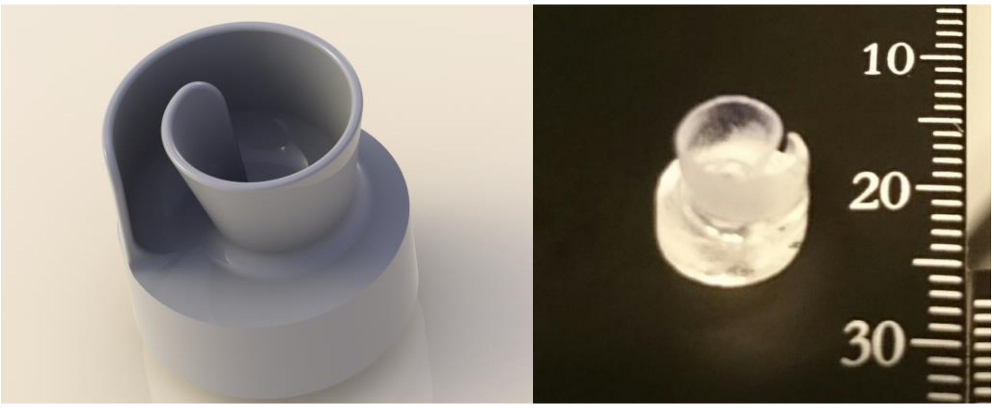

Figure 2. Illustrates a self created part in Autodesk Inventor and its 3D printed physical model with transparent material

2.6.2: Download a 3D model

As an alternative to creating their own 3D model, students could 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. The STL (STereoLithography) file format is a format commonly used for 3D printing, and describes a 3D surface built up of triangles. We found this step to be 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 was considered as a motivating tool for students as they could get some idea of how the device is functioning. Another example of an impeller in 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 and a Formlabs 3D printer (see figure 3).

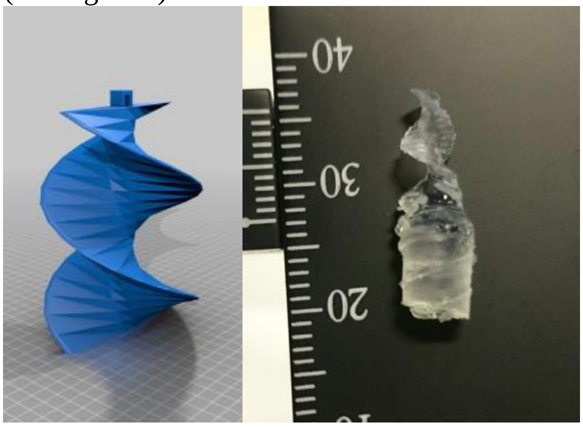

Figure 3. Showing an example of a downloaded 3D model from Thingivers.com

2.6.3: Making a 3D model based on MR/US/CT modalities

A 3D model based on any imaging modality as magnetic resonance imaging, 3D scanning, ultrasound imaging or computer tomographical imaging techniques gives mostly DICOM imagery. Converting these files to a STL formats usually introduces challenges as noise that may be considered to be part of the model and vice versa if one is not familiar with anatomical properties of the object that has to be printed. As an example, we have a micro CT image of the maxilla tooth that had to be converted to a STL format and printed. Figure 4.shows how the unfiltered file looks like and how the two different results from a formlabs 3 D printer (transparent color) and a maker boot 3D Printer (white color). At this step, if the students do not have the anatomical understanding, the process will not motivate them to go any further. There is still no doubt that 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 familier 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 result will look like at 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 something; where to move, how fast move and what path to follow. It is possible to tweak this automated process with enough coding experience, but this is very time consuming.

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 an example of a micro CT (computer tomography) image of human tooth with its printed results from Formlabs printer (transparent) and 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. This process can normally be time consuming and takes from several minutes to hours depending on the physical size of the model. Although the previous steps have been done carefully, there is still a chance of dissatisfactory results. Smallest changes to the printer environment is enough to result in total failure. We have experienced that humidity, room temperature, level and stability of the table that the printer is resting on, can contribute to bad prints. 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 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 involved and it may confuse the students. A step by step 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. The students were motivated to produce their desired objects, whether those objects were practical or novel in nature. For most of our students, 3D printing was merely a means to achieve a goal. Hudson et al. 2016 also confirms the same as our observation [4]. 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 [7,8,9], finding that it provided students with hands-on experience and increased student motivation, performance and information retention. Additionally, Buehler et al. [10] 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 experiences confirm the results of Beuhler et al (op.cit.) but also shed light on other challenges with medical 3D printing where the knowledge of anatomy is important. Although some of our students are familiar with 3D modelling in addition to anatomy and physiology through courses at our department, we believe this knowledge cannot not help them to meet the challenges of combining two fields. This may act as a demotivating factor for the students. We believe that the challenges mostly come into play when the design has to meet complex requirement specifications for medical applications. The suggested work flow is particularly designed for this purpose. However, we may not know if the model gives the same motivation results for engineering students in other fields and a further research has to be conducted. Several case studies have investigated experiences installing 3D printers in public and university libraries [11,12]. These cases provide some insight into how these print centers 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 centers.

5 CONCLUSION

There is no doubt that 3D printing especially for medical applications is challenging. We believe that our paper has contributed in highlighting where the significant challenges may occur in a systematized workflow. The goal of education as a path to employment or to personal fulfillment is still debated, and the question of whether it is possible, or even desirable, to institutionalize an emerging technology in education remains. If nothing else, 3D printing with the current workflow presents an opportunity to encourage the students to complete their projects.

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