Learning by Making. 3D Printing Guidelines for Teachers

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Abstract For many years now, and particularly since the 1930s, educational research has focused on the idea that all authentic education comes from experience. Nowadays, activism has found a natural affinity with the maker movement. Fab labs and creative ateliers have become more popular, especially for educational purposes, suggesting the coming of new types of “learning by doing.” However, these new forms of “learning by doing” must take account of the technologies already present in a particular creative space used by makers. These technologies are mainly: 3D printers, CNC milling machines, 3D scanners, laser cutters, etc. This short paper begins with a premise of educational ergonomics, to introduce teachers, media educators and *animatori digitali* (digital coordinators) to the didactic implications of introducing different human–machine interfaces (HMI) into their practices. In particular we describe the main features of SLA and SLS 3D printing. The impacts we discuss of 3D printing are resolution, types of printing materials, average printing times, post-processing, and cost. We have selected these criteria because it has been documented that their impact is very heavy in certain school subjects. For example, an FDM 3D printer can be useful in terms of the ease of printing an object, but it may not reach the necessary level of detail for a meticulous reproduction of art objects or precision mechanisms that an SLA 3D printer can achieve.

Keywords 3D printer · Slicer · Didactics · Fab lab

1 Introduction

In recent years, educational research has seen that the technology used to design and support processes in development and engineering can also stimulate teaching–learning in general terms, but particularly in certain subjects. Moreover, the spread of digital manufacturing spaces and the increasing popularity of the maker movement [1] appear to have opened up new theoretical and practical possibilities for

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pedagogical activism [2–5]. However, the educational potential of digital manufacturing spaces is contingent on a proper understanding of all the distinctive features of the technologies that are found in these spaces. This short paper aims to introduce teachers and, more specifically, media educators and *animatori digitali* (digital coordinators) to digital fabrication, through a focus on educational ergonomics [6]. We look at the didactic implications of employing the different forms of HMI [7] that can be found in 3D printing technology. This work analyzes two widely used 3D printing technologies, namely fused deposition modeling (FDM) and stereo lithography apparatus (SLA), and suggests what the implications of their educational use may be in terms of: resolution, possible printing materials, average printing times, post-processing, and cost. The criteria in this list were selected on the basis of documented experience [7]; they significantly affect applications in different subjects. 3D objects can be designed in CAD software of varying complexity, such as Autodesk Fusion 360 (a free version is available for students and educators), Rhinoceros 3D, SugarCAD, and Tinkercad. Fusion and Rhinoceros are designed for professional use, whereas SugarCAD and Tinkercad are more suited to educational use because they have easy-to-use graphic interfaces. After the 3D model is created, it must be imported (usually in .stl file format) into a slicing program, which will “slice” it into a series of thin layers or 2D levels, in preparation for 3D printing. Slicing programs also allow users to set basic parameters for printing, such as, the type of filling, the thickness of each level, the number and thickness of the external “walls,” extruder temperature, etc. The most popular software programs for slicing are: Ultimaker Cura, Slic3r and Simplify3D (the first two are open source). After slicing the model, these programs create a G-code file, the de facto standard format, which can be used with any kind of 3D printer.

2 Fused Deposition Modeling (FDM) 3D Printers

Fused deposition modeling printers use thermoplastic material to print 3D objects, which they achieve by pushing melted plastic through an extruder and depositing it on a printing plate (see Fig. 1). There are different types of thermoplastic materials (generally filaments) on the global market, which differ in terms of their properties (i.e., resistance, elasticity, magnetic and aesthetic properties). FDM technology is probably the most widespread and inexpensive, on account of the printing materials it uses and the cost of the machine itself. This kind of printer is useful for creating 3D objects that need cantilever parts or support structures (scaffolds) during printing (see Fig. 1). However, the layer resolution is not very high, and printed objects can appear rough and unrefined (see Fig. 2). Support structures are substrates of material that are printed to enable the extruder to print curves and protrusions. This prevents molten material from falling onto the printer base. More specifically, support structures have predefined forms (determined by the software), or can be customized by the maker. Some FDM models have a double extruder and can print support structures from water-soluble materials. In this case, once the support structures have been

Fig. 1 FDM (right) and SLA (left) 3D printing technologies

Fig. 2 The same object printed with FDM (left) and SLA (right). *Source* <https://www.3dhubs.com/knowledge-base/key-design-considerations-3d-printing>

printed, they can be dissolved in water, leaving no residues on the final model. It could be inferred from the above, that, given the many restrictions on printable shapes, the design process is not completely free with FDM technology. A double extruder completely eliminates the issue of residues and inaccuracies caused by support structures, but resolution and the properties of materials are still something to take into account (e.g., when printing a building model to scale, some elements, like pipes, cavities and other details, are too small for FDM 3D printer resolution, and have to be redesigned). On average, the maximum resolution of a non-industrial FDM printer in terms of layers is about 0.2 mm (not considering small movements

on the printer's x and y axes). This resolution is affected by other factors, such as filament material and model, temperature, humidity, extruder problems. These factors can also have a negative impact on the replicability of the 3D model produced. Therefore, although FDM technology is an excellent opportunity when learning to design simple objects, it is not suitable for detailed elements. SLA printers, which usually have higher resolutions, allow makers to overcome this limit.

3 Stereo Lithography Apparatus (SLA) 3D Printers

Stereo lithography apparatus (SLA) technology uses photoreactive resins. SLA 3D printers operate with an excess of liquid plastic that is solidified by exposure to light from a laser or a projector (see Fig. 1). As with FDM technology, SLA printers build 2D layers to create 3D objects designed in CAD software, but the physical process is completely different. SLA printers have a laser that solidifies each layer, one after another, starting from the top of the 3D object. This means there are more issues relating to supports than with FDM technology, which require more expertise and attention on the part of the maker during the design phase. Even cantilevered parts can be printed without support structures in FDM, but almost all shapes need a scaffold with SLA technology. Indeed, almost all 3D objects printed with SLA need a support structure, whereas many objects can be printed in FDM without one. Also, SLA technology and resins are often more expensive than equivalent materials in FDM. There are numerous kinds of SLA resins, each with its own physical and aesthetic properties. Finally, the maximum resolution in SLA printing is (on average) 0.025 mm.

4 FDM Versus SLA: A Comparison for the Teaching Setting

Summarizing and extending our previous considerations, SLA technology offers makers more opportunities because it produces higher 3D resolution; however, more time has to be spent on the design of models. Another consideration is that SLA does not have some of the issues that FDM has: molten material deposited on the printer base; quantity of extruded material; filament pulling, etc. For these reasons SLA printer technology has a resolution of 0.025 mm instead of the 0.2 mm found in FDM technology. Consequently, SLA technology can print complex objects (such as dentures for dental technology courses). However, increasing the resolution of a 3D object means increasing post-production time.

Although FDM printing sometimes requires post-production processes to eliminate inaccuracies and vertical lines caused by the thickness of the layers or by non-water-soluble supports, the post-production and post-processing times for SLA

printers tend to be longer on average. Models produced by SLA printers have to be “cured” in two stages. In the first stage, the 3D object is exposed to ultraviolet rays to finish the solidification process, and in the second, it is sanded to eliminate any marks where the supports were held. To summarize, makers should consider the final purpose of their 3D object when deciding which 3D printer technology to use. FDM printers with dual extruders provide greater design freedom and produce reasonable results when detail is not important (e.g., toys, medium-sized gears, boxes and containers, etc.). This makes FDM technology ideal for educational settings, where it can be used to introduce the basic concepts of CAD design, and for printing scientific or mechanical objects that do not exceed the maximum resolution parameters. SLA printers, on the other hand, do not provide maximum design freedom, because they rely on support structures that are sometimes difficult to remove. For this reason, SLA is not recommended for teaching CAD design, and SLA printers are recommended for 3D objects where detail is important (e.g., reproductions of monuments, jewelry for art institutes, and, as mentioned, dentures for dental technology courses, etc.).

5 Conclusion

We finish this short paper by mentioning some of the many repositories containing files of 3D printable objects that are available on the internet for free download. These include Thingiverse, MyMiniFactory, Pinshape, Cults, GrabCad, CGTrader etc., and have entire sections dedicated to educational purposes. These repositories often contain information to help makers on: (1) which 3D printing technology is most suitable for the model; (2) what settings to use during printing. These online 3D model repositories are a good starting point for learning about and appreciating 3D printing, and for getting a better understanding of SLA and FDM technologies, their similarities, differences, opportunities and trends. Lastly, we would like to clarify that we have focused on FDM and SLA technologies in this paper because they are both suitable for mainly non-industrial uses. Other technologies, such as SLS, DLP, SLM, and MSLA, are too expensive for educational purposes.

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