Making by printing – disruption inside and outside school?

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Abstract  
This paper considers the possible impacts of additive layer manufacturing (3D printing) on current global socio technical systems concerned with the manufacture and distribution of goods and how the introduction of this technology might disrupt the secondary school technology curriculum.

Introduction  
This paper explores the possible consequences of making available to students in secondary school a technology as it is beginning to be disruptive in the world outside school. The technology under consideration is additive layer manufacture sometimes known as 3D printing. This paper is in five main parts. First it will describe the nature of additive layer manufacture. Second it will consider the nature of disruption in the context of technology. Third it will consider the extent to which additive layer manufacture has the potential to be significantly disruptive of prevailing socio technical systems. Fourth it will consider how this technology might disrupt current practice in secondary school technology education. Fifth it will consider arguments for and against introducing this technology into the secondary school curriculum.

Additive layer manufacture  
The Centre for Additive Layer Manufacturing (CALM) at Exeter University defines additive layer manufacturing (ALM) as:

A modern fabrication process that can use a wide range of materials to create products ranging from medical implants to parts of an aircraft wing. Three-dimensional parts are built up in two-dimensional layers as little as 0.05 mm thick; this way of building parts offers great flexibility and opportunities for creating new products at low cost, whilst reducing the carbon footprint associated with manufacturing. (http://emps.exeter.ac.uk/engineering/research/calm/)
Digital files describing products can be sent anywhere in the world where there are customers with 3D printers. The manufacture of those products at those sites, as opposed to manufacturing in bulk in one place and then transporting to customers in different places, reduces transportation costs and hence impact on the environment. The data used to define the layers to be deposited starts in the form of a digital description of the item to be produced and is then converted very quickly by software into an STL (Standard Tessellation Language) file, which software in the 3D printer turns into a precisely described set of layers. These layers are then printed, one on top of the other. CALM provides a brief history of ALM on their website at http://emps.exeter.ac.uk/engineering/research/calm/whatis/history/

The technology has grown from its inception in the late 1980s, when it was considered to be a means of rapid prototyping using thermosetting plastics, to the present day where the process can deal with a much wider range of polymers and metals to produce finished products. Significantly, the technology is now seen as a means of manufacture as opposed to simply prototyping. Current work is preparing the supply chain for potential demand for products using these processes.

What is a disruptive technology?

According to Christensen (2012) ‘disruptive technology’ is a widely used and generally accepted term but a more accurate term is ‘disruptive innovation’ because market disruption has been found to be a function usually not of technology but rather its changing application. A ubiquitous example is the automobile. While a revolutionary technological innovation, it was not, at its inception, a disruptive innovation because early automobiles were expensive luxury items that did not disrupt the market for horse drawn vehicles. The market for transportation essentially remained intact until the debut of the lower priced Ford Model T in 1908. Henry Ford (1922) indicated his intention to be disruptive as follows:

I will build a car for the great multitude. It will be large enough for the family, but small enough for the individual to run and care for. It will be constructed of the best materials, by the best men to be hired, after the simplest designs that modern engineering can devise. But it will be so low in price that no man making a good salary will be unable to own one – and enjoy with his family the blessing of hours of pleasure in God’s great open spaces. (p 73)

The mass-produced automobile was a disruptive innovation, because it changed the transportation market. The automobile, by itself, was not. It is in the situation of changing application that additive layer manufacturing finds itself and which might lead to it becoming disruptive.

Will additive layer manufacturing be a disruptive innovation?

In England the Technologies and Travel Project (http://www.lancs.ac.uk/tnt/) funded by the Economic and Social Research Council (ESRC) and undertaken by Lancaster University, and the University of the West of England, Bristol (UWE) hosted a one-day scenario building workshop around the future effects of computer-aided design and additive manufacturing and their possible consequences for global patterns of both freight transport and consumer travel. The workshop presented four possible scenarios described below, each dependent on the extent to which there was either high or low engagement with 3D printing and either high or low corporatization of 3D printing. These scenarios are shown diagrammatically in Figure 1.

Scenario 1 Desktop factories at home

The technical possibilities of fabrication in the home using desktop 3D printers significantly disrupted global systems of production, distribution and retailing. Many factories in the global south closed or downsized. Yet many supply chain and distribution networks remained intact and have even been consolidated due to rapid growth in demand for powders and other feedstocks for ‘printers’.
Scenario 2 Localized manufacture
There has been a blossoming of high-street retail bureaus or ‘print shops’ to cater for the trend in use of online networks of 3D designs organized through large scale corporate databases developed by suppliers such as Google or Amazon. Global manufacturing and distribution has grown from these new business opportunities with emerging supply chains of material feedstocks due to localized manufacturing on a vast scale. Much manufacturing ‘returned’ to the global north and this has reduced the large-scale transport of objects from the global south.

Scenario 3 Community craft
Growing up in a knowledge economy with easy access to new technology has meant that community groups championing 3D printing innovated and experimented through informal networks based around local innovation. Most people continue to procure consumer items in the traditional way either through online purchasing and delivery from distant manufacturing centres or through retail high-street stores.

Scenario 4 Only prototyping
Although many types of 3D printers were developed, hardly any made a successful market entry, with the products being of too low-quality or too expensive. As a result, most people continued to depend upon online and traditional retailers for the purchases of goods that were manufactured in ‘factories’ often very distant from these consumers. Rapid prototyping remained the main use of 3D printing technologies and this had little impact upon transport or travel patterns.

Scenarios 1 and 2 have the potential for significant disruption to the prevailing socio-technical system of manufacture and distribution. In scenarios 3 and 4 the current system in which the majority of goods are produced in the global south and transported to the global north is main-
tained. Some have already indicated their scepticism with regard to scenarios in which there is disruption. Dean (2012) Editor-in-Chief of Develop 3D describes how he used an inexpensive 3D printer (£1500.00) to manufacture a bracket for his weather station – the original had been broken by windy conditions. A highly successful experience for Dean but he was not persuaded of the viability of scenario 1. He writes, “I'm still not convinced that there truly is a mainstream market for 3D printers – people just don't, in the majority of cases, want to get involved in making their own stuff.” (p. 66). Welch (2012) has suggested that all kinds of people make all kinds of stuff – cakes, rock gardens, quilts, shelves for the garage, model aircraft etc and that Dean misjudges peoples' 'makerliness' although whether 3D printing would appeal to the hands on making described by Welch is debatable. One argument against this is that 2D printing used to be a specialist occupation but with the advent of home computers many people are quite comfortable with designing and printing fully illustrated documents as well as high-quality photographs. The pervasive nature of home printing is also indicated by most on-line businesses offering printable versions of relevant documentation. Is it possible to that 3D printing will grow in the same way as 2D printing? Maly (2012) argues that typography in the early 1900’s typography was a heavy industry involving the forging of fonts yet in less than 100 years homes and small businesses are quite comfortable carrying out their own printing. Given that 3D printing is in its infancy, only 30 years old, Maly argues that it still has plenty of time to mature and become pervasive as did 2D printing.

Scenario 2, localised manufacture, is gaining credence. Whilst the use of additive layer manufacturing has been used for rapid prototyping as a means to reduce lead-time prior to manufacture it is now being used for production. Twenty percent of 3D printing is now thought to be of final products rather than the printing of prototypes (Kross, 2011). General Electric has announced that it will intensify its focus on additive manufacturing to develop a variety of products, from aircraft engine components to parts for ultrasound machines (Cox, 2011). Markille (2012), writing in The Economist in an article entitled “The third industrial revolution”, asserts that the geography of supply chains will change. Markillie cites the Boston Consulting Group, who speculate that in areas such as transport, computers, fabricated metals and machinery 10–30 percent of the goods that America now imports from China could be made at home by 2020, boosting American output by $20–55 billion a year (Markillie, 2012).

Hence scenario 2 has appeal to those who wish to see a revival of manufacturing in the global north. This scenario also has appeal to those who wish to solve the global problems of resource depletion and climate change by moving towards a circular economy (Ellen MacArthur Foundation, 2012). The transport of goods from centres of mass manufacture by means of containerisation in extremely large cargo ships contributes to the amount of carbon dioxide in the atmosphere. If goods were produced at or near the site of consumption the amount of carbon dioxide released through transportation would be reduced although this begs the question of the transport of the material required to print the items. Once printed items had reached the end of their useful life it would not be difficult to return them to the technical nutrient stream to be reused in printing other items. If this could be carried out without significant loss then resource depletion would be reduced. Some however are sceptical. Mims (2012) considers that the notion that 3-D printing will on any reasonable time scale become a “mature” technology that can reproduce all the goods on which we rely is to engage in a complete denial of the complexities of modern manufacturing. He argues that 3D printing will have the biggest impact within traditional factories. Mueller (2006) has foreseen this position and considers that 3D printing will be used to develop multiple design possibilities for parts and enable limited numbers of products to reach market whilst tooling up for conventional manufacture to take place.

**Disruption of current practice in secondary school technology education**

Williams (2007) takes the position that one of the purposes of technology education is to prepare school students to engage in a participatory democracy and that Web 2.0 provides some interesting possibilities because it provides services which students readily access and become familiar with.
and (citing O’Reilly 2006) are characterised by open communication, decentralization of authority, freedom to share and reuse, user’s ownership of data and an effectiveness that develops as people use them. Steeg (2008), building on Williams’ advocacy for Web 2.0, argues that a possible future for technology education involves engagement with tools for personal fabrication linked to on line hacker/maker communities. Since 2008 a clearly identifiable on line 3D printing community has emerged and some members of this community are shown in Table 1.

Given the access to the Internet available to schools it is possible that students could use such organisations in two ways:

- Developing simple digital designs for products, which the organisation prints and then sends to them by post – the school and/or students would need to pay for this service;
- Developing simple digital designs for products which the organisation prints and sends by post to others who are prepared to pay for the design – the school and/or students would make money from this service.

In neither of these cases is it necessary for the schools to possess a 3D printer. The students would be involved in designing but not making, although it would be possible for them to acquire made versions of their designs. The making function would have been devolved to one of any number of on-line 3D print bureaus. If such a ‘designed by me but made by somebody else, somewhere else’ practice became widespread in, for example, England, it would be a major departure from prevailing practice where pupils are invariably required to make what they have designed. If it became well established it would be disruptive.

If a school possesses a single 3D printer then it is possible for students to develop digital designs and print them on-site but this is not without its problems. The size of the work bed in school-based 3D printers is small, making it impossible to print multiples of student work. Printing is also quite a slow process (the bracket printed by Al Dean took several hours). Hence it takes a long time for a class of students to each print what they have designed. Some models are not that reliable so there is a steep learning curve before the printers become simple to use. However, it may be possible to overcome these difficulties. Recently the company A1 Technologies has given this matter some thought and concluded that a different approach is needed. First, there needs to be a much more reliable 3D printer that is straight-forward to use in the low cost part of the market. Second, it would make sense for schools to buy several such 3D printers so that pupils would be able to parallel process their printing. To this end Martin Stevens, the CEO of A1 Technologies has designed such a 3D printer – the Maxit 3D kit printer made available in kit form which takes less than a day for a pupil (rather than a technician) to assemble, as opposed to a week for other 3D kit printers, and devised a modern manufacturing ‘set’ which consists of six Maxit 3D kit printers, six laser scanners, six haptic design packages, one Studiomill 5 axis milling machine, all necessary software plus cutting and printing material plus curriculum materials for students aged 11–18 for an overall price of some £23k (€28k).
At the time of writing, this set has only just been made available. It remains to be seen as to whether schools will buy into this approach to making 3D printing available although there is a significant track record of A1 Technologies selling smaller volumes of their products into schools. Consider students aged 12 – 13 years, the age at which such students are taught computer assisted design and become familiar with the use of 3D modeling software to ‘design on screen’ (Winn in press). At the moment such students in most schools would not have access to the computer assisted manufacturing facilities that would enable them to make what they had designed on screen. If the school purchased a modern manufacturing ‘set’ a class of 24 such students would be able to work in groups of four with each group having their own 3D printer. The students could work both collaboratively and individually in developing designs to be printed. They would also be able to download free of charge open-source digital designs and either print as is or modify and then print. If such a ‘designed by me and printed here’ practice became widespread in, for example,
England, it would be a major departure from prevailing practice where students are invariably required to make the products they have designed using hand and manually operated machine tools. If it became well established it would be disruptive. It would make assessment difficult. The collaborative nature of the on screen designing would give difficulties in assessing student’s individual progress. The nature of the making taking place, being completely under the control of the 3D printer would also problematise the assessment of student’s making skills. Note that there has been criticism of secondary schools in England that do not use modern technologies in their curriculum (Ofsted 2011, 2008).

Discussion

Crawford (2010) decries the closure of shop classes in the United States and celebrates the learning and self efficacy that come from the knowledge and skill that enables someone to understand and be able to repair their technical possessions. This has considerable resonance with the practical activity of designing and making that constitute the heart of many school technology programmes. If these programmes move to the point where the designing is done on screen so that the artefact can be made by additive manufacture the physical interaction between the hands, tools and materials and the hand eye coordination required to acquire mastery will to a large extent be lost. It is a question of breadth and balance. Introduction to and experience of modern manufacturing processes, such a 3D printing, should not be at the expense of denying students the experience of working with tools and materials. However it is important to realise that even if time and money can be found to introduce 3D printing into the technology curriculum without compromising or marginalising conventional designing and making activities the work carried out might be difficult to assess under current assessment requirements.

If 3D printing does become disruptive in the world outside school, then there is a further argument for including it in a technology curriculum. An important part of technology curriculum is the exploration of the relationship between technology and society through which students achieve an understanding of the socio-technical systems that operate in the world. The introduction of containerisation in the 1970s has resulted in a world container fleet of over 3000 vessels (Cudahy 2006). Recently Maersk announced plans to produce a new range of ‘mega’ triple-E container ship 20- storey high and as wide as an eight-lane motorway and taking four-five days to be unloaded (Vidal, 2011). The cargo container is part of a wider socio-technical system shaped by global production, consumption, provision, investment inequality, status and wealth (Birtchnell & Urry, in press). It is rare that a practical activity involving designing and making can be used to give insight into such large-scale socio-technical systems. There is the possibility that as students engage with a technology that disrupts their experience of school technology that same technology is also disrupting what happens in the world outside school.

At the time of writing Techfortrade a UK charity has announced an educational challenge with regard to 3D printing. Techfortrade has a mission to alleviate poverty through technology-enabled trade. Its aim is to act as a catalyst for new ideas; working with innovative projects that have the potential to scale and replicate. The 3D printing Challenge aims to find transformational uses for additive technology that deliver real social benefit in the developing world. During May 2012 there are workshops to support the challenge in New York, London, Johannesburg and Nairobi. The competition is aimed at identifying ideas worthy of further funding and taking them to market (Techfortrade, 2012). There is no reason why students could not be engaged with this challenge as part of their school technology curriculum. This would provide them with the opportunity not just to consider the disruption that is taking place in the world outside school but contribute towards such disruption. This indeed would be an interesting example of the participatory democracy through technology education advocated by Williams (2007). This has some resonance with the ideas of Facer (2011) who has argued that in the face of new and emerging technologies schools will need to redefine themselves as places in which communities debate and decide on the futures they wish to create for themselves.
The possible significance of 3D printing for both the world and technology education indicates that it will be worth carrying out empirical research into the impact this technology has on school technology education. The following research questions may be worthy of consideration:

To what extent is 3D printing being used in secondary schools?

What are the constituents of a 3D printing curriculum?

What impact does the introduction of 3D printing have on the rest of the technology curriculum?

What do stakeholders in the technology curriculum think about the introduction of 3D printing into the curriculum?

The author would welcome discussions with colleagues who are interested in pursuing these questions.

**Conclusion**

Despite some scepticism (Dean 2012, Mims 2012 and Mueller 2006) there is a groundswell of informed opinion that 3D printing will be a disruptive innovation that will have profound effects on global trading. Birtchnell and Urry (in press) imagine a future world of fabrication ‘that is not something that would simply replace long supply chains and containerization. Rather the proliferation of 3D printing may change the overall ecology of machines and technologies’. This is of course speculative and uncertain but if their vision should become a reality there is the real possibility that students in secondary school may be able to use this technology in a future in which this technology contributes towards disruption of the socio technical systems of the wider world and the technology curriculum.
References


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