3D printing interdisciplinary learning for complex problems


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Chapter 5
3D Printing Interdisciplinary Learning for Complex Problems

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ABSTRACT

Since the initial introduction of 3D printing as a prototyping tool for pupils studying practical technology subjects, its use has rapidly expanded over the last few years as educators have started to explore its potential as a teaching tool in diverse subjects. Yet it is possible that its potential as an educational tool lies beyond the innovative subject-specific applications currently under development, in a more expansive role as a catalyst for interdisciplinary educational practices. This chapter considers the possibility that 3D printing provides a platform for interdisciplinary educational experiences, aligned to scholarship on the development of significant learning experiences grounded in practice and the empowering of learners through changing relationships in the classroom, for engagement with complex problems across traditional subject boundaries.

INTRODUCTION

3D printing, known industrially as additive manufacturing, is predicted to be a significant and disruptive technology for the twenty-first century because of its potential as a catalyst for far-reaching social, economic and environmental change (Anderson, 2013). This is due to its anticipated impact on the future of manufacturing and the democratisation of making, enabled by corresponding advances in digital communication technology. Within schools and universities, however, it is predominantly viewed only as a useful making tool. Based on examples of teaching strategies for current learning imperatives, this chapter highlights the potential of the technology to provide a platform for interdisciplinary education that engages with complex problems across traditional subject boundaries. This approach aligns to scholarship on the importance of authentic learning experiences, grounded by real world issues. According to Starko (2010, p.16) “an authentic problem (a) does not have predetermined answer, (b) is personally relevant to the investigator, and (c) can be explored through the methods of one or more disciplines.” This chapter aims to support the strategic use of 3D printing as an entry point to interdisciplinary col-
laboration and engaging with educational challenges emerging in the twenty-first century. The chapter will be relevant to educators in schools and universities across disciplines and also curriculum developers, assessors and policy makers.

BACKGROUND

3D printing was initially adopted by universities under the banner of additive manufacturing with predominantly high-end machines utilized in doctoral research in engineering and medicine. However, the subsequent development of low-cost 3D printing technology and specific initiatives providing low-cost printers for schools, for example by Mcor technologies (2014) and Stratasys (2016), has led to its increased use in the last five years. The original educational printer, the RepRap, was designed in 2005 by academic Adrian Bowyer from Bath University in the UK as an online, open source, low-cost 3D printer using single nozzle, fused deposition modelling (FDM). Once one printer was built, the idea was that it could then be used to print the next one, and so on. Although the printer itself was fairly delicate, it was adopted by independent makers and in schools and universities as a good introductory tool for the technology. Its advantage was the independence of making it allowed students because its running costs were low. In addition, from a health and safety point of view, it was low risk. As commercial FDM 3D printers became more affordable, there was a shift from open source as 3D printers entered the mainstream market and education. By 2016, according to the 3D printing industry advisory company, Wohlers Associates, 278,000 FDM desktop printers were estimated to have been bought (McCue, 2016). This spread of low-cost printers is part of a growing maker movement, with 191 Maker Faires in 38 countries in 2016 with an attendance of 1.4 million people (Wolverton, 2017). Neil Gershenfeld (2005), the Director of the MIT Center for Bits and Atoms, had launched FabLabs in the 2001 using low-cost commercial desktop 3D printers as part of a suite of digital fabrication technologies designed to expand access to new technologies for the general population. By 2018 there are approximately one thousand recognized FabLab facilities around the world. This democratization of making (Lipson and Kurman, 2013) aligns with the growth of design thinking, where participatory design and co-design shifts the emphasis from professional designers to design collaborations (Van Abel, Evers, Klassen & Troxler, 2011). Desktop printers began to become more common in classrooms after 2010 when they became commercially available (rather than relying on the RepRap model), though mostly at first in design and technology education. By 2017, however, desktop FDMs were used in classrooms in schools and universities across a variety of disciplines (Ford & Minshall, 2017). Even so, perhaps because of the initial emphasis on high-end machines in the technical disciplines or because of the fallibility of the initial desktop printers, or possibly because of the link to the democratization of making and a perceived threat to professional design jobs, product design academics have been slower to engage with the technology than might have been expected (Loy, 2018). Although the technology allows for the rethinking of manufacturing that is very relevant to designers (Gibson, Rosen & Stucker, 2016), 3D printers have mainly been added to university product workshops just as an additional tool, much like an extra drill press or router. There is little evidence of a specific emphasis on working with the technology in its own right or understanding design for 3D printing to any degree of sophistication outside engineering and medicine. In many cases, universities do not actually teach the students how to work with 3D printing beyond safe practice, relying on a peer to peer approach for the students to develop their knowledge. This keeps the technology firmly as a prototyping tool, unlike processes such as injection or rotational moulding where students
are taught the constraints and opportunities of the technologies for professional practice. Interestingly, this has resulted in the dominant form of learning about desktop 3D printers being on line via forums, blogs and videos. There is an argument that this is fostering a proactive, lifelong learning approach.

Where professional development is provided for teachers, it tends to be in short, one-off workshops designed to inspire and provide basic knowledge, but rarely does the professional development provided for teachers and academics on working with this technology go much further. Without more advanced learning opportunities, academics will struggle to place digital technologies such as 3D printing at the center of educational learning. Instead they remain supplementary to it. It is possible that educators are missing the potential of digital technology to support the new learning approaches needed to create new perspectives for the next generation, in response to the impacts of the digital revolution created by the rise in digital technologies at this time. According to Cameron (2017, p.83) the digital revolution as a whole is not being addressed in education as it should be “the education/skills training implications of engaging seriously with the disruption scenario we are discussing stand out as immediate challenges for policymakers thinking ahead. The industrial economies have never experienced anything like it.” Since its initial introduction as a prototyping tool for students studying practical subjects, such as design and technology, the use of 3D printing has expanded into a wide range of subjects. Yet it is possible that its relevance as an educational tool lies beyond subject-specific applications in a more expansive role as a primer for interdisciplinary educational collaborations addressing the teaching of change and complexity in this increasingly interconnected, digital age. Because of the growing interest in engaging with 3D printing across disciplines, there has been a growth in the number of academics who use the technology, as well as its associated digital technologies, such as 3D scanning and accessible electronics. This means that educators should now be better able to respond to the potential of 3D printing as a primer for new learning perspectives. The underlying research supporting this chapter considers how educators can build collaborations between the disciplines as a catalyst for new thinking suitable for twenty-first century learning. By demonstrating how this can be applied in practice based on 3D printing, the examples outlined in this chapter provide starting points for discussion on the opportunities that a focus on digital technologies as transformative could bring. Specifically, the focus is on developing learning experiences that could stimulate a paradigm shift in thinking in response to complex, interdisciplinary topics.

TWENTY-FIRST CENTURY EDUCATION

The question of what learning should look like, feel like and be about at this time is the subject of debate (Trilling & Fadel, 2012; Beetham & Sharpe, 2013). The digital revolution during the first decades of the new century have pointed to an educational revolution, with a shift to a complex web of open access, interconnected, interdisciplinary, flexible learning for all with ongoing, universal updates fed by social and technological change. Yet massive open online courses (MOOC) have so far largely failed to deliver, or sufficiently evolve to respond to this promise (Liyanagunawardena, Parslow, & Williams, 2014; Lankshear, 2014) and organising interdisciplinary learning as a coherent whole, rather than a series of disjointed activities, remains difficult (Lin, 2008). Whilst the challenges of rethinking education for the complexities of living in the hyper-connected, digital era are still being addressed, Cameron’s (2017) argument that educators are failing to recognise and respond sufficiently to the radical change currently underway needs to be addressed. One of the reasons for this disconnect is that whilst evolving digital
technologies over the last twenty years have provided new communication platforms for universities, the content remains relatively unchanged.

Designing learning for the twenty-first century requires an objective view of the world as it is now and the impact of digital technology on traditional disciplinary practice, then a rethinking of how to approach significant learning development in a significantly changed world. In addition, research suggests that the transmission or lecture model is still prevalent as an instructional approach in education (Scott, 2015, p.2) even when enabled by digital tools, rather than being rethought. Although there are academics who have embraced digital technology in schools and universities in terms of creating pedagogy that responds to the opportunities it provides, for example with the gamification of learning (Dicheva, Dichev, Agre & Angelova, 2015) Scott (2015) argues for more meaningful, enquiry-based learning that has relevance for students and their communities to a much greater extent. Without significant development in the curriculum itself for twenty-first century learning, the outcomes will continue to fail to respond to the fundamental changes the digital revolution is bringing to the world. Whilst digital tools can create new delivery modes, they are also part of a bigger discussion on how digital technology is changing global and community interactions. Interdisciplinary study, termed curriculum integration, has been highlighted by McPhail (2018, p.58) as a strategy that could provide an “important component within the international discourse concerned with school reform”. McPhail described it as a change in twenty-first century learning, refocusing curricula on bigger picture themes and issues. He suggests it fosters greater student engagement as it can be organized around broader ideas and questions that are more relevant to students and the world beyond school. However, the understanding informing this approach has been challenged by Albrecht and Karabenick (2018) as their research into relevance for learning and motivation in educational learning strategies suggests that there is a lack of consensus on what constitutes relevance for students in education. Their recent article discusses the lack of agreement on the purpose of educational institutions in the twenty-first century, and whether their role is to be relevant for students or for society, arguing that problems arise when educational relevance is not framed on the students’ individual interests primarily but on society’s broader agendas.

Interdisciplinary Learning

Whilst debate continues, overall there is growing acceptance that conventional learning within traditional disciplinary silos is inadequate in providing learning experiences that prepare the next generation in terms of their personal development, their role in society and industry and to address the complex problems that an increasingly interconnected world brings. Many universities - and even schools - have developed interdisciplinary, cross-disciplinary, multi-disciplinary or transdisciplinary programs to create a level of curriculum integration. Alternatively, they have introduced newly defined fields, such as creative intelligence, entrepreneurship or innovation that operate across disciplines. The intention with these programs is to provide learners with the opportunity to build new skills and understandings that are not bound by conventional disciplinary thinking. There are, however, significant issues with these strategies. These include deciding who teaches the first generation of programs and how educators can arrive appropriately armed with a wealth of interdisciplinary experience and how learners can establish depth and rigor in their approach when their cross-disciplinary work by definition cannot be informed by agreed disciplinary knowledge built up over time. There is also the issue of deciding what the programs should include and how interdisciplinary they should actually be. Interdisciplinary learning and enquiry-based learning have become intertwined. This is because meaningful, enquiry-based learning
by its very nature is unlikely to be constrained within traditional discipline boundaries, but the evolving relationship between interdisciplinary learning and enquiry-based learning in this twenty-first century digital era needs continuing attention to ensure its academic rigor.

Major academic disciplines, each with an accompanying body of knowledge, have evolved over time into established fields of practice. Additional research has incrementally been added to each body of knowledge, becoming broadly agreed upon throughout each discipline over the last hundred years where research has been widely disseminated through publications. Over the last thirty years, however, digital technologies have challenged the fundamental assumptions within disciplines and the digital revolution has challenged accepted ideas, structures and business practice. For example, digital technologies will impact the future value of an individual’s mathematical ability in civil engineering with the growing emphasis on generative modelling and computational simulations. Similarly, in the legal profession, search engines are replacing much of the work completed by paralegal analysts and in stock broking, algorithms are automating trades. In journalism, both automation and the ability of individuals to upload images, video and commentary to the Internet are undermining traditional knowledge and accepted practices within the discipline. If academia fails to address these changes, education will become increasingly irrelevant, but equally, creating appropriate responses is difficult. What academics will need to do, however, is to recognize that digital technologies are no longer supplementary to the educational experience, but rather central to changes in society and therefore conduct academic research into evaluating the new worlds that digital technologies are creating and how to operate within them to ensure that the epistemological educational imperatives are appropriately revitalized.

Digital Technology

Society needs education that provides informed, critically engaged views of the world for the next generation. The digital revolution has created rapid and unexpected change, from new issues in political communication, such as the changes in practice by the current US administration’s use of twitter, to retail operations with the rise and influence of Amazon. One of the major issues facing current educators is how to understand, rationalize, frame and address these changes. Whilst a top-down approach, based on research into the broadest implications of digital change, is important, there is also a need for researchers to engage with a bottom-up approach, to understand specific situations in order to build a body of knowledge that can inform strategic practice. Without this engagement as its foundation, any top-down approach will remain speculative. Drawing on the development of sharing platforms such as Wikipedia and version control software for multiple contributors, such as Git, it would now be possible to build a shared body of research where individual topics could be explored and added to a constantly developing body of knowledge online. This would change the nature of academic research, how learning in a discipline is designed, and also how it is ultimately kept alive. Learning design will be impacted by digital technologies, particularly in relation to:

- **Worldwide Communication**: There is no longer a filter or lens that can control how information is provided. This brings with it issues on the veracity of information, and the weight of the sheer volume of information. How to support future generations in critical engagement with the mass of information is an educational driver.

- **Interactions**: Different ways of expressing and sharing of ideas and providing immediacy in forums for discussion driving iterative development.
• **Complex Problem Framing**: Digital technologies are affecting all disciplines, and therefore established strategies for understanding complex problems will need to be re-examined.

• **Complex Problem Solving**: Digital technologies are providing new ways of responding to problems that cut across disciplines and draw on new ways of seeing and interacting, as well as creating and resolving solutions iteratively.

• **Curating a Body of Knowledge**: New ways of working create new directions and focus, new criteria and new authentication.

If education was a new phenomenon and designed to be appropriate to the realities of contemporary society, it is an interesting question to consider how it would differ from current offerings. There is evidence of educational practice evolving in response to new societal realities and aspirations in recent years. In the UK, for example, the introduction of technology schools, based on the Thomas Telford model of providing personalized pathways for children whose progression through school was interrupted, is a realistic response to the realities of contemporary life. In Bali, the Green School addresses the issue of what should be taught by integrating into the curriculum strategies for reconnecting students with the land, growing food etc. In Australia and the US, there is a growing body of research on the re-introduction of risky play to challenge the developmental restrictions placed on children in recent years. Digital technologies are frequently utilized in education practices in current teaching, but rarely are they highlighted as integral to developing new teaching philosophies and yet they are critical to the lives of populations across the world. Recognising that the digital revolution has changed the world is the first step to creating authentic educational experiences for the twenty-first century. Scott (2015, p.13) states that “the research evidence is conclusive: enquiry, design and collaborative approaches to learning build a powerful combination of content understanding, basic skills and applied twenty-first century skills.”

This chapter presents the argument that digital technologies can provide new ways of working for interdisciplinary educational experiences aligned to scholarship on the development of significant learning experiences, grounded in practice and the empowering of learners through changing relationships in the classroom. This is because 3D printing provides a neutral starting point for all disciplines, for students engaging with complex problems crossing traditional subject boundaries.

**3D PRINTING NEW LEARNING**

The term 3D printing refers to around forty different processes that share the characteristic of being based on a layer-by-layer build fed by a 3D computer model. 3D printing is part of a suite of digital technologies for data generation, communication, monitoring, fabrication and analysis that together are changing the nature of making and interaction. As these technologies continue to evolve and costs continue to fall, their adoption across disciplines is likely to increase. However, rather than as part of educational ontology and planned strategies, in reality technologies such as 3D printing have been introduced into schools and tertiary institutions over the last ten years by individual teachers and enthusiasts. This has resulted in the disjointed, incremental adoption of technology into education. Yet they have the potential to provide support for broader learning ideologies related to interdisciplinary learning in a digital age, with 3D printing a good example as a nexus for new learning rather than a supplementary fabrication tool for traditional teaching strategies. Lipson and Kurman (2013), in their book, Fabricated, argue that with 3D printing in particular, it is the responsibility of academia to take a long-term view of the impact
of the technology. Scott (2015) recommends that the integration of technology in learning experience design depends on seeing the technology not as a sole solution, but as an enabler that contributes to the culture of learning and collaboration in the classroom. Publications written about the use of 3D printing in education focus on the role of 3D printing as an accessible tool for students in the production of model making (Loy, 2018). However, if 3D printing is made the focus for framing a learning experience, with the technology studied as a catalyst for change, that in itself provides the basis for creating relevant, interdisciplinary learning in this digital era.

**Framing Practice: Future of Work**

Engaging with this approach involves placing digital technology at the center of the learning activity, rather than in a support role. This could be applied to a range of digital tools, including communication tools, sensors, data analytics etc. In this chapter, taking 3D printing as the core learning tool, rather than a fabrication tool only, focusses the activities on the technology’s broader role as a disruptor, rather than its functional role in supplementary making. In order to allow students to think about the implications of this without disciplinary boundaries, it is recommended to bring together a mixed group of students from a diverse set of disciplines.

The application of this approach in practice was demonstrated in a workshop run within a Masters of Business Administration (MBA) in Griffith University, Australia. The learning challenge was how to encourage the students to grasp the implications of disruptions in social, economic and environmental interactions caused by digital technologies in the twenty-first century. It was an evening program, with a large cohort employed in different industries, from nursing to utilities to accountancy. Approximately ten percent of the students identified as having seen an FDM 3D printer operating, but none had experience of a high-end machine, such as a metal printer. None of the students in the cohort could describe examples of how the technology could be used in their specific field. The students were provided with a demonstration of desktop 3D printing and took part in an interactive lecture and applications review to introduce them to the technology. Correlations were made between the disruptions created by other digital technologies (Van Abel et al., 2011) and the pivotal role that 3D printing could play in disrupting conventional manufacturing - for example with the digitization and print-on-demand of spare parts. The students were then organized into their industry sectors (health, finance, utilities etc.) and asked to work out how 3D printing with associated digital technologies could affect business operations in their business sector.

It was interesting that in the first instance the groups focussed on mundane uses for the printers, such as for small, temporary repairs. It was only after challenging the students as a single cohort to work together through the examples they had identified, that the transformative potential of the technology began to emerge. For example, the nurses initially thought of small products such as clips that could be useful in their work but agreed as a group that it did not have the potential to create any radical change to their working practice. However, when the class reformed as a cohort, students who were working in the utilities sector described how they thought the technology could be used in call-outs to remote regional areas to provide temporary products, such as conduit covers, until the appropriate product could be supplied. The nurses then debated whether this could be a useful strategy for creating basic medical tools in remote regions. To move this discussion forward, students were then introduced to the work of Melbourne-based company, Anatomics (Izatt, Thorpe, Thompson, D’Urso, Adam, Earwaker, Labrom, & Askin, 2007), which is a company specialising in medical implants and surgical tools using 3D printing.
They were shown 3D printed surgical cutting and fixing guides and how they were developed based on the surgeons practicing on numerous 3D printed facsimiles of the bones to be operated on, to provide the surgeon with guidance during the actual surgery. This approach aims to improve the accuracy and speed of the clinician during complex surgery. In the following discussion, students thought these could be useful in telemedicine (diagnosis and treatment at a distance enabled by digital communication tools) and they became enthusiastic about debating the pros and cons of this idea. This led to the students’ realisation that this could potentially lead to surgeons planning operations that were carried out by others – potentially nurses. This created a sudden shift in perspective in the group. From changing their thinking of 3D printing, from an additional making technology being considered in a limited, conventional way as a tool, to view its potential to enable radical change, the students caught a glimpse of a completely different way of seeing the activities of their profession. This shift in perspective changed the parameters of the discussion within the cohort, with students proposing new ways of working and interacting based on digital technology that challenged accepted practice.

The workshop objectives related to stimulating new ways of seeing enabled by digital technologies. By focussing on guiding students in interrogating 3D printing in itself for its role in making change, the students were led towards a paradigm shift in thinking. Cameron (2017) suggests that the exponential growth in digital development is currently too extreme for individuals to comprehend or respond to, the situations that are complex. There is a need for learning strategies to help address this issue and provide ways for students to engage with the paradigm shifts that accompany the digital revolution, rather than just its technical aspects. This MBA workshop provides an example of a learning strategy that breaks students out of their established disciplinary thinking and see the bigger picture.

**Addressing Complexity: Sustainability**

According to Gore (2013), sustainability will be a key issue for humanity in the future. It is a global imperative and can be a difficult topic to address in education because of its scale and complexity. The workshop example shows how it was introduced through 3D printing in an interdisciplinary learning environment. The project was run as a twelve-week, first year course based in a design program at Griffith University, Australia, but open to all students across the university as long as they also enrolled in, or had completed, a complementary 3D computer solid modelling class. Ostensibly it was an introduction to 3D printing, but the course objectives focused on providing the students with an engaging, interdisciplinary learning experience on sustainability through an interrogation of the technology in today’s society. The approach was not limited to considering 3D printing as a making tool, but rather as a starting point for students to work from, with each study direction researched and evaluated through the lens of sociocultural, environmental and economic sustainability. By starting this way and working outwards, rather than starting with a broader view of sustainability and considering how 3D printing might be used to address issues within it, students retain control over the breadth and content of the subject.

Sustainability study fits as a significant learning topic for students as all future citizens will be responsible with regards to sustainability issues and need to be able to develop an informed response. However, there are practical, social and emotional factors that can undermine its choice as a learning topic, particularly in regards to emotive issues, such as ocean pollution. There are very complex, global issues involved with a myriad of factors that make sustainability difficult for students to comprehend with any depth, or for teachers to know how to start to address with any rigor as a learning activity. The realities of the situation and students’ own, ongoing contributions to problems identified during
sustainability studies can create feelings of guilt that are not supportive of empowered learning. It can be overwhelming for students and therefore feel intractable, with their efforts diminished into futility. This would inevitably be disheartening, with students feeling as though their study was an academic exercise only, rather than a genuine attempt to research, map, understand and address real world problems relating to sustainability in any meaningful way. 3D printing provided an effective vehicle for this course example for a number of reasons. To begin with, it was neutral territory. No student saw it as being solely their disciplinary domain. This allowed the academics and students involved to establish a shared language across the cohort. Also, as it is a rapidly developing technology academics were able to set up an empowered student-centered learning environment by not positioning themselves as the experts on the technology, but rather asking the students to research new applications as they happened week by week, contributing to positive in-class discussions. This was in order that the students could lead the discussions and the academics learn alongside them as collaborators. This was an important element in setting up the classroom dynamic so students could feel confident enough by the end of the course to express their own ideas on the direction they had followed in their work. This was needed as each students’ work could lead to a very different outcome to that of other students. Fostering proactive learning was considered an essential component for this course in helping students to tackle interdisciplinary problems because of the lack of an established, directly relevant body of knowledge available for them to consult.

The course did not start with how to use the technology, or its basic use as a prototyping tool or as a supplement to existing processes. Instead it was positioned as a central catalyst within the emerging digital revolution. The first lecture drew parallels between the work of Ford and the impact of the moving assembly line on the organisation of labor and urbanisation and the possible work futures enabled by the development of digital technologies. The students were initially provided with a fairly utopian vision of distributed manufacturing, print-on-demand, the digitisation of inventory, iterative post-launch product development and customisation, with the current limitations of the technologies minimised to allow for divergent thinking in the early stages of the project. The examples provided for discussion included the Fingerprint light by Dan Yeffet and the co-design operations of companies such as Nervous System, where parametric models are provided for customers to adapt to their liking before printing.

The students were then provided with examples of where the technology has created innovations in business practice and asked to map the ecosystems around those examples. These highlighted the different ways of working the technology could provide. The emphasis was not on looking at 3D printing as a fabrication tool but rather placing it within the suite of emerging digital technologies, such as in relation to communication, monitoring and distribution, and the digital revolution they are bringing about. Students were given readings on societal changes, for example on the densification of cities, the creation of smart cities, and the rising cost of healthcare. Framed in this way, the students would identify the transformative aspects of the digital technologies working in concert, rather than their individual functional capabilities as part of existing systems. This approach was established within the course, and students were encouraged to direct their thinking to new ways of working. The discussion was directed towards aspirations for society in the twenty-first century and in particular responding to the sustainability imperative outlined by Gore (2013) and Hawken (2018). In this way, the challenges being faced were framed more positively because whilst trying to change people’s behavior, take-on big business interests and understand the complexities of life-cycle assessment in relation to sustainability can be too difficult for an individual student to comprehend. When framed within the context of major changes happening at this time that are doing just that, it becomes less impossible to imagine being able to construct a useful
response. By focussing on the democratisation of making and customised production 3D printing allows, the student is better able see production, consumption and recycling in a more personal and manageable context. Just as online platforms such as Kickstarter and GoFundMe demonstrate the economic power of individuals operating collectively, by seeing the impact of an individual as part of the collective in relation to sustainability strategies made possible by 3D printing, concepts such as extended producer responsibility should have more meaning. Essentially, the key reason for using 3D printing as a starting point for this course was because it provides a vehicle for framing the sustainability challenge within a cognitively and emotionally manageable situation. The preparation study on 3D printing positions it within a suite of digital technologies that are changing the way people interact with each other, the world around them and means of production, distribution and consumption. By providing students with a new perspective on the power to radically change interactions and systems that the digital revolution has provided, they are arguably better able to address complex or messy problems with optimism. They are also better equipped to consider the interdisciplinary context of the situation based on their preparatory research into transformation technologies.

The environmental debate is conducted in a predictable cycle: Scientists discover another negative human impact on the environment. Trade groups and businesses counter, the media reports both sides, and the issue eventually gets consigned to a growing list of unresolved problems. The point is not that one side is right and the other wrong but that the episodic nature of the news, and the compartmentalization of each successive issue, inhibit devising solutions. (Hawken, Lovins & Lovins, 2005, p.309)

According to Powley (2018), the atomisation of learning in the classroom designed to meet the pedagogical requirements driving educational assessment at this time has resulted in the underplaying of the holistic element of instruction. The learner-centered teaching approach advocated by researchers such as Blumberg (2008) and Weimer (2013) supports holistic learning, but the realities of working with open-ended projects with large cohorts and not breaking the activities down into discreet elements is challenging. 3D printing has the potential to be a catalyst for holistic thinking on changing practice, in response to environmental sustainability in particular, as it allows for a shift from mass production to print on demand. Combined with associated digital technologies, such as 3D scanning, the Internet and generative design, 3D printing provides a good starting point for learning activities designed to support critical thinking about established manufacturing and consumption practices and explore new ways of working in the future.

The emerging potential for using 3D printing is illuminating some of the inefficiencies in mass production: the stockpiling of components and parts, the large amounts of working capital inspired for such stockpiling, the profligate waste of materials, and of course the expense of employing large numbers of people. (Gore, 2013, p.31)

Whereas conventional production requires an upfront investment in tooling that means products are produced on mass and designed as generic in order to maximize sales, 3D printing requires no preparatory tooling and allows the design of high value, customized products. In industry, 3D printing for light weighting (reducing the material used within a part) and part consolidation (consolidating parts into a single structure that removes the need for assembly) are contributing to the response of companies in meeting sustainability and performance targets, for example in aerospace by GE Additive. In the broader
community, 3D printing has the potential to decentralize manufacturing and reduce waste through the shift from mass production to printing on demand. This would be a positive starting point for students considering environmental sustainability in the face of the scale of pollution as described by Decker (2014, p.83) in her book The Plastic Ocean “During the 2012 Cleanup, volunteers found enough food packaging for someone to get takeout for breakfast, lunch and dinner every day for the next 15,000 years.”

Fundamentally, the critical point is that new digital technologies are allowing for a rethink of human interaction and patterns of production and consumption. This needs to be part of education for the next generation. The approach described in this chapter is more difficult to facilitate than a conventional learning experience and relies on learning outcomes that relate to the students’ ability to research and create connections rather than produce resolved solutions.

**Advancing 3D Printing in the Classroom**

Working with low cost 3D printing in classrooms in schools and universities on a practical level as a making tool has been well documented (e.g. Thornburg, 2014, Loy, 2015) and there are numerous examples of practice in individual subject areas, such as the work of Henry Segerman in visualising mathematics, the 3D printing of topographic maps in geography (e.g. Hahn, 2017) and the examples of projects for the classroom provided by 3D printing companies such as Stratasys. This chapter does not focus on the practical challenges of working with 3D printing in the classroom, but rather the use of the technology as a starting point for addressing open-ended, complex problems across disciplines. However, in order to understand the possibilities and limitations of the technology beyond the basics of low cost printers, new professional development programs will need to be developed for teachers to introduce them to the range and capabilities of high-end machines, their applications and the implications for the future of work and society. Without the opportunity to experience first-hand printers for processes such as polymer selective laser sintering (a laser melting and fusing method used in industrial 3D printers) and direct metal laser sintering for titanium, steel and aluminium, or work with technologies, such as desk-top carbon fibre printers, the discussion in classrooms will remain at a basic level. Universities need to provide greater access to high-end technology for school teachers and academics from different disciplines to ensure that education for the next generation is professionally informed.

**SOLUTIONS AND RECOMMENDATIONS**

Cameron (2017) observes that individuals find it difficult to imagine that radical, disconcerting and disruptive change will happen and how it might look. Developing learning activities to help students to look forward in a constructive way is a challenge, but essential for the rapid changes that are happening with the evolution of the digital technology ecosystem and its impact on society. Interdisciplinary learning activities are needed to break down traditional silo thinking and, in particular, learning activities that focus the academics and students’ minds on changes brought about by digital technologies and their future impact to prepare the next generation for the changes that are still to come. Designing these learning activities, however, is a challenge. Based on the experiences informing this chapter, recommendations for working with 3D printing on designing these significant, interdisciplinary learning experiences to complement discipline specific learning include:
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- Provide opportunities for students to lead the learning activities based on their 3D printing research.
- Ensure that the activities are designed to still value their disciplinary knowledge whilst participating in interdisciplinary activities.
- Create a shared language that is not discipline specific but provides a glossary of terms relating to digital technologies and transformation.
- Where possible, have an element of hands-on activity using 3D printers in the class, so that the students have the reality of the technology as a solid foundation for the more speculative aspects of addressing interdisciplinary projects and challenges that work across social, environmental and economic concerns.
- Emphasize the students’ roles in navigating human evolution in a technological era based on critical thinking.

FUTURE RESEARCH DIRECTIONS

Further research is needed into epistemological direction for learning in relation to the complex, interdisciplinary changes that are occurring due to the digital revolution to inform the ontology of twenty-first century education. This is necessary to help prepare successive generations to be able to address the radical changes predicted for society with the impact of factors such as the rise of artificial intelligence and machine learning, ageing populations and environmental degradation. As Gore (2013, p.xv) points out in the introduction to his book, The Future, “there is a clear consensus that the future now emerging will be extremely different from anything we have ever known in the past. It is a difference not of degree but of kind.” Technology tools, such as 3D printing, provide a solid basis for engaging students in critical thinking about topics that are difficult to grasp and are not confined within traditional subject boundaries. Research building on the approach outlined here could further connect the ecosystem of digital technologies currently creating change. In addition, educational research into the professional development of educators in schools and universities on the implications of connected digital technologies on the human experience will be of benefit for twenty-first century learning.

CONCLUSION

The discussion presented here on 3D printing in education is about positioning it not in terms of teaching new skills, but in supporting new ways of seeing for twenty-first century challenges and developing interdisciplinary practice. 3D printing is without question a good addition to workshops, but its ability to enable the relocalization and distribution of bespoke manufacturing facilitated by digital platforms and its impact on re-patterning social, environmental and economic interactions is far more critical. In the examples described, the underlying intent was to help students step back from the immediate, in order to try to experience a paradigm shift in their thinking to capture some of the intangibles of new ways of operating in this digital era. The specific shift was not intended to be the end in itself, but rather to support students and researchers in thinking beyond their current experience and the constraints of their established discipline and accepted knowledge boundaries. In challenging the participants in all the examples to consider what are the implications of radical, integrated change, the use of 3D printing
as central to the learning activity rather than as an adjunct, provided a springboard for shifting the focus to the bigger picture implications. 3D printing may seem to be a single tool, but the reality it is that it is at the center of the digital revolution, a catalyst for significant change. Education in the twenty-first century needs to be reimagined, and 3D printing provides a starting point for interdisciplinary learning about the complex problems for society today.

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REFERENCES


3D Printing Interdisciplinary Learning for Complex Problems


ADDITIONAL READING


**KEY TERMS AND DEFINITIONS**

**Additive Manufacturing**: The industrial term for 3D printing encompassing a wide range of technologies that build objects from 3D computer models without the need for tooling.

**Authentic Education**: Used to describe learning activities that are based on projects that are meaningful to the participants.

**Bespoke**: In this context refers to objects that are customized specific to a person or situation.

**Direct Laser Melting**: Refers to the laser-based melting and fusing of metal powders in additive manufacturing.

**Fablabs**: These are open access, makerspaces set up as a linked network around the world by Neil Gershenfeld, the current Director of the MIT Centre for Bits and Atoms.

**Lifelong Learning**: Refers to a current trend of education planning for ongoing, cumulative learning rather than for finite, discrete modules.

**Relocalization**: In this context refers to a policy of supporting distributed manufacturing rather than centralized manufacturing, cutting down on the environmental impact of transporting goods and supporting local economies.

**Selective Laser Sintering**: A laser-based method of melting and fusing material used in the industrial 3D printing of polymers.
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