PROJECT PARTNERS

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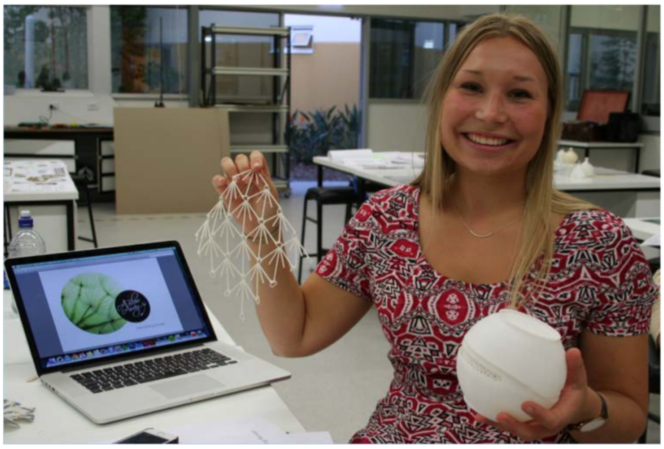
Case study 6.
Enhancing student learning through rapid prototyping and testing: 3D printing technologies across disciplines



Summary

This case study describes how 3D technologies are used to extend technology teaching and learning. Students are able to use 3D design and printing to physically make objects. 3D technologies offer a number of advantages for students including:

- Multidisciplinary: 3D technologies are being used with students across a variety of disciplines.
- Moving from the digital realm to the physical: students are able to design their ideas and then print them in 3D. Students move through multiple redesigns to refine their objects in order to make them into a physical form.
- Freedom to design: students are given the freedom to design what they feel is important to them. This approach to design has enabled students to produce 3D heart models, speaker housing for a prosthetic leg, dentistry tools, future furniture, new fabric constructions and intricate fine detail work not possible with conventional construction ideas.

Keywords

eMaking; 3D design; 3D printing; rapid prototyping; additive manufacture; workshop instruction

What worked?

This case describes how students from a variety of disciplines including art, engineering, dentistry and medicine have used 3D technologies as part of their learning. Students use 3D design and printing technologies to design and make their own physical objects. The process of using 3D technologies is termed *making* and the International Society for Technology in Education (ISTE) suggests that the "maker movement values human passion, capability and the ability to make things happen and solve problems anywhere, anytime" (Martinez & Stager, 2014, p.2). In using eMaking technologies, students are not only learning to use digital tools but are also extended to making objects physically with the use of 3D technologies.

Learning by making has a long history with technology-related subjects in higher education, including pre-service teachers learning how to teach technology; art students fabricating creative objects; and engineering students moving a digital design from concept to fabrication. More recently, higher education has been moving away from workshop practices because of health and safety concerns including: increased supervision requirements leading to liability concerns; increased running costs; and a lack of student enthusiasm for workshop environments (Loy, 2014).

Many university students use digital technologies in their personal lives, and now those students studying design-related courses might be expected to spend more time in the virtual world of design in preference to physically building in a workshop. The construction approaches of the past have relied on the use of materials, such as foam or cardboard to create ideas physically, but 3D printing technology has changed the learning landscape to make construction more intuitive via the use of 3D design software. 3D printing builds on the students' digital confidence rather than requiring them to work with unfamiliar materials. To illustrate, Loy (2014) indicates that 3D design allows students to "realise the sophisticated models they imagine, based on their expertise in 3D computer-based modelling, not based on their skills in the traditional workshop" (p. 110). Loy, who was a key lecturer in this case study noted,

> *I encourage them as soon as possible to print something…It shouldn't be resolved…the magic happens as soon as they see a physical object come out.*

While Loy is essentially a lecturer within the Queensland College of Art, connections can be made with other discipline areas such as engineering, medicine and dentistry. Consequently, students are not restricted in the creation of the physical objects. They are able to "reconnect to making, and with confidence in their ability to create physical objects from concept, students are then able to bridge into workshop practice through conventional introductory workshop skills" (Loy, 2014, p. 111). She encourages students to be original,

> *It takes the students a while to get their heads around it…I am a great believer in right from the word go, you do your own thing.*

Making and design are "an interactive process where students develop concepts through research, reflection, drawing, studio model-making and workshop prototyping" (Loy, 2014, p. 111). One of Loy's students, who was interviewed for this case, confirmed,

But it's up to us to provide all the research, depending on the path we want to take with it…[it] allowed you to explore different options…You can look at it from all sorts of angles. (Postgraduate student)

3D design software has significantly improved in recent years, and 3D design and printing enables students to translate concepts into reality. This is in contrast to past practice, whereby design and construction tended to be separated both in the curriculum and also in the teaching space. 3D design software was often used as a documentation tool at the end of the design process, but there are now greater opportunities to print designs and test design conceptualisation. A student explained the design process and how she developed critical thinking skills as part of the process,

Part of being a designer is also thinking about your orientation and thinking about how the shape actually looks and you've got to put full thought into actually how you're going to make it…I like thinking about my shape, the thing I'm going to create, how I'm going to make it and then critiquing how to make it an then always trying to find the best sort of production technique. (Undergraduate student)

From 2013, a workspace purposely designed as a 'digital hub', has been created for students where they can design and build in the one space. Students can "discuss and develop ideas on screen and through the physicality of form and structure…[they] can work seamlessly between drawing, sketch modelling, online research, computer modelling and digital fabrication in a learning cycle that moves their design thinking forward with more self-determination" (Loy, 2014, p.112). On two visits with the 2014 class, the students were observed working on computers, 3D printing, and discussing products with peers and with the lecturers in the room. The room was laid out with standing height desks in clusters of four with 3D printers in a dedicated room. The lecturer advised that the 3D printers were usually moved from the printing room to the centre of each cluster for every lesson to enable the students to work in groups around a 3D printer.

3D printing has changed how students produce their work as, in the past, students likely constructed 'one-off' moulds with materials supplied by the university, but now they can use any design to create elaborate fine-detailed creations that were not possible with previous materials. Loy (2014) states "rules for creating forms and structures are different and the applications are breaking traditional discipline boundaries, opening new directions for 3D designers to work in" (p.113).

You design it and that's not just a design on a computer that you forget about. It's something that you can have and hold. (Undergraduate student)

As 3D printing is still a new emerging field, credible 3D printing publications are not abundantly available and so students and the lecturers look to the growing amount of material on the internet, thus changing the boundaries on who possesses the knowledge within the learning environment. A lecturer interviewed for this case explained,

> *So I found that group in particular who were our second years, just kept coming to me with all the information and saying "look, this is happening, have you seen that?" I seriously could not keep up with that and it was really exciting. (Lecturer)*

This change in knowledge ownership has allowed a change in the approach from directly teaching content, to teaching filtering and interpretation of content in order to determine what is or is not valuable. As the field of knowledge on 3D design and printing is changing rapidly, new quickly becomes old for the next cohort of students. This change in practice encourages the lecturers to engage in individual student learning rather than a focus on cohort teaching. This in turn leads to a deepened student-lecturer connection that can aid in reducing student attrition and overcome what Race and Pickford (2007) have described as a growing disconnect between higher education students and lecturers.

3D printing students are no longer working with old approaches or designs using old technology but rather are challenged to create new ideas understandings and approaches. The use of a classroom or workshop where students are encouraged to use their own technology to complete their design work allows the students to continue learning outside of the workshop and then return to physically test their designs after they are printed,

> *It was my choice and I didn't need to make so many models…It interested me and I liked seeing the results. Every other week I'd come in and get something printed. It's exciting to see it materialise. (Postgraduate student)*

Learning is not constrained to the university or classroom where students may feel disconnected from their future world of work. As students are not able to keep objects printed on campus, students are made aware of where they can have their designs printed outside of the university. The 3D printing providers are introduced to the students as they allow students to print their designs at an industry-subsidised cost with advanced materials that may not be available for use on campus (Loy, 2014). As part of the process, the external printers provide feedback about the design before printing. This connection with the 3D world beyond the university can connect students with future employers or give them the ability to produce objects that they can show future employers. An undergraduate student said,

> *Having an actual physical product as part of my portfolio has given me the confidence to show employers something a bit more tangible and then that portfolio I was able to present to a company and are now currently working for them.* (*Undergraduate student*)

Students have the option to be able to open their own accounts, upload their own models (without lecturer supervision) and have it checked by the 3D printing provider; this gives students objective feedback on the viability of their design in terms of printing. This has changed the learner focus from reliance on the lecturers to partnerships with experts.

Future students will be able to print using more advanced 3D printing as the university has purchased a new $300,000 3D printer. With the increasing growth in the number of students in the course, it is anticipated that more students from traditional 'making' disciplines and students from other disciplines will want to use 3D technologies to make new and unanticipated objects.

Why it worked

Enablers

There were a variety of factors that enabled the use of 3D technologies in this case study. This section highlights important factors that have emerged from the data or have been observed by the researchers in compiling this case. These include:

The establishment of the digital hub: Careful consideration of 3D printing facilities and the design of the space are critically important enabling factors. Moreover, building the capabilities of staff and students to use these facilities is important.

Developing protocols for access to and use of the 3D printers: Designs are required to be checked before printing on university 3D printers. Students have the option of printing using externally provided 3D printers at their own cost. External 3D printing staff are able to provide objective/constructive feedback on designs before printing.

Teaching and learning approach encouraged innovation and creativity: A feature of the learning design is that the students are encouraged to work on their unique designs within and beyond the classroom setting. Assessment design also gives students scope to design an object without being constrained by predetermined lecturer requirements. Assessment criteria of the quality of the design of the products encourage innovation and creativity.

International connections and partnerships enhanced learning opportunities: Partnerships with external organisations enable additional enhancement and opportunities for students for 3D printing, as well as on campus. Students are given agency and are encouraged to use external 3D printing organisation to review and print work.

Showcasing student work motivated students: Student work is used to demonstrate the potential of 3D technologies on and off campus and for national and international competitions. These showcase opportunities motivate students with the knowledge that their design solutions have an audience and are competing with other design products.

Challenges

There are several challenges in relation to the use of 3D technologies. This section aims to highlight specific challenges that were reported by participants or observed by the researchers to have a direct implication for the enactment of the TEL and which may be relevant for other institutions to consider in deciding to use 3D technologies. These include:

Designing and creating a dedicated space for 3D printing: In this case study a dedicated space was required for 3D printing. In the past, a shared 3D printing space was located at another campus and the printer was unreliable. More recently, a dedicated space was developed on another campus with all students from other campuses required to travel to the campus to use the 3D printers. Therefore, locating the dedicated space according to single and multi-campus institutions is a challenge.

Printing time needs to be addressed: 3D printers are slow and printing jobs can take hours and sometimes days to complete. Solutions need to be developed to manage printing capacities.

The challenge of new knowledge in an emerging field: As 3D printing is a new field, few publications and texts are currently available although there is an emerging research and knowledge base. The participants in this case study addressed this issue by networking with others in this emerging field, and also engaging in research and publications which share insights into practices.

Limitations with technical and professional development support for 3D technologies: In this case study there has not been adequate support for 3D technologies within the university. Advocacy for improved support is needed.

What the research literature says

The 2014 Higher Education Edition of the NMC Horizon Report highlighted two important considerations regarding the future of additive or maker technology in higher education:

1. There will be a shift from students as consumers, to students as creators. This will be a mid- range trend driving change in higher education within three to five years; and
2. 3D printing, horizon predicts this technology will be adopted within two to three years. (Johnson, Adams Becker, Estrada & Freeman, 2014)

The Horizon report suggests that 3D printing is causing a shift in “pedagogical practices on university campuses all over the world as students across a wide variety of disciplines are learning by making and creating, rather than from the simple consumption of content”

(Johnson, et al., 2014, p.14). This growth is not restricted to workshop-based learning but rather to all disciplines across universities where students are encouraged to create evidence of hands on learning by encouraging "media creation, design and entrepreneurship" (p. 14). The report emphasises the importance of creating spaces that are purposely designed to integrate content and production as part of the learning experience. The costs associated with making have decreased significantly providing students' access to a wider range of resources that enable students to translate designs into reality.

3D technologies provide students with the tools to move their maker object from digital to physical form. From its early and expensive beginnings, 3D software and printing have become more affordable for widespread use in universities and for students to own. 3D printing is described as building,

> *a tangible model of prototype from the electronic file, one layer at a time, through extrusion-like process using plastics and other flexible materials, or an inkjet-like process to spray a bonding agent onto a very thin layer of fixable powder…Using different materials and bonding agents, colour can be applied, and parts can be rendered in plastic, resin, metal, tissue and even food". (Johnson et al., 2014, p. 40)*

According to the *NMC Technology Outlook – Australian Tertiary Education 2013-2018* (Johnson, Adams Becker, Cummins, Freeman, Ifenthaler & Vardaxis, 2013), 3D printing was reported to have an adoption period of two to three years. In the more recent 2014 NMC Technology Outlook – Australian Tertiary Education 3D printing was not reported in any category. There was no explanation for why it had been dropped from the list.

The eMaking movement has its theoretical underpinning in Piaget's constructivism and Papert's constructionism. Constructionism emphasises that learning occurs when something is actually constructed whilst constructivism centres on learning as a social process, and includes interactions with the environment and self-reflection (Duchesne, McMaugh, Bochner, & Krause, 2012). Constructivists believe that learning occurs when students build on previous knowledge in a social environment and that educators need to recognise student's previous experience and knowledge in designing learning. Designing with 3D technologies enables students to construct within an environment where they communicate with others (lecturers and students) who in turn enrich the experience by providing valuable resources, support and direction (Fosnot, 1993). Duchesne et al. (2012) propose there are four key principles of constructivism: active participation; self-regulation; social interaction; and individual sense-making.

Active participation in eMaking is explained by Loy and Canning (2012) in suggesting that students "need to be empowered to interact on a more fundamental level with everyday objects, to develop their understanding of construction and deconstruction, material behaviours and characteristics" (p.20). In order for them to design new objects for the future, it is necessary for them to understand the lifecycle of the objects they currently use in everyday life. This provides a "new, grounded approach to understanding what goes into the production of everyday and complex user objects and implications for their design and construction" (p. 20). As we live in a world where resources are finite, new ways of thinking about design, where objects are designed for the complete lifecycle including production, deconstruction and reclaiming of materials, are needed.

Learners are self-regulated as 3D design and printing allows students to design and physically test their products in order to determine the best design, via an iterative process, whereby they try "something again and again until it works, and then once it works, making it better" (Stewart, 2014, p.4). The end products are more complete or resolved objects that are submitted as assessment but are also ready for the real world of manufacture. Martinez and Stager (2014) suggest that eMaking brings about change in students and develops their passion, capability, and ability to construct and solve problems. Students "start to believe they can solve any problem…learn to trust themselves…who don't need to be told what to do next" (Martinez & Stager, 2014, p. 2). 3D technologies enable students to explore design with their own ideas that might not exist as manufactured products.

eMaking occurs in a new learning environment that combines digital and physical learning. No longer is design completed in computer labs and separated from making spaces as the " link between screen and reality provides an opportunity to engage higher education students with making again" (Loy & Canning, 2013, p. 15) so that "students can work seamlessly between drawing, sketch modelling, online research, computer modelling and digital fabrication" (Loy, 2014, p. 112). Students are able to design on computers and move to physical creation in the same learning environment. Workshops or *makerspaces* or *fablabs* (fabrication labs) (Martinez & Stager, 2014) are designed to encourage social interaction between lecturers and students where they can move from design to fabrication in the same learning environment.

eMaking allows students to explore the construction of objects and to construct their own meaning that they can test in design and manufacture. Students are not regurgitating the lecturer instruction disguised as learning but creating their own learning where the lecturers facilitate the learning in the learning space. eMaking changes the role of the lecturer from instructor to facilitator, as students do not need explicit teacher-led instruction for learning (Martinez & Stager, 2014; Loy, 2014, 2011; Loy & Canning, 2012).

3D printing offers many opportunities to change the manufacturing industry from mass production of multiple components to an approach where components are printed when they are needed, not stored or shipped from central warehouses as 3D printers that can be housed locally (Loy, 2014). This can dramatically change the view of sustainability conscious manufacturing of the future. 3D printing allows for customers to co-design or customise their design so they create a unique product. These students will play a leading role in the 3D printing revolution.

Moving forwards

Participant advice

In this case study the lecturers and students interviewed advocated several key 'methods of success', that could be considered when thinking of using 3D technologies:

New skills for lecturers - students suggested that lecturers needed to develop a new set of skills to incorporate new eMaking technologies. Their suggestions reflected a strong constructivist pedagogical approach and re-thinking of technology education. There were suggestions that changing assessment practices were required from lecturer prescribed scenarios to students themselves being required to identify a context for eMaking.

Needs a dedicated space - an eMaking space where there is access to 3D printing, WiFi and computers with access to design software. The space must contain furniture that enables computer-based and physical eMaking and should also encourage collaboration with lecturers and other students.

Budgeting for the cost of the 3D technologies and printing -there is a substantial cost involved in buying the latest design and 3D printing technology, and the cost of setting up a dedicated space. It was suggested that students' designs are checked before printing to minimise wastage, eMaking can be expensive for students if they need to 3D print outside of the university and particularly eMaking can consume considerable amounts of time on design and manufacturing. For students, the cost of purchasing and maintaining their own technology (software and hardware) is significant.

Consider the range of student design knowledge - as students with a wide range of design knowledge and background can enrol, it was suggested that it is important to build learning activities which cater from beginners through to those with design knowledge. There are positive opportunities for including students from different disciplines as they can develop 3D printing design solutions in new areas, for example, Dentistry students were enrolled in the course.

Engage in the eMaking community - lecturers and students suggested that a "shared community of learners" approach enabled students to seek help when investigating new eMaking opportunities and provide support to peers by sharing experiences. For lecturers, publishing and research helps to build a knowledge base for eMaking.

Institutions moving forward

- Institutions need to acknowledge that students from many different disciplines want to learn using eMaking, but they may not have had any prior 3D design experience. One approach is to match students experienced with 3D printing with aspiring students to overcome the hurdles of design when thinking about 3D printing, and allow students the freedom to design to encourage innovation and creativity.

- Develop eMaking learning spaces where students can learn, design and make while collaborating with lecturers and other students. Considerations about the context in terms of single and multi-campus institutions are needed to enable spaces which are accessible to students at their campuses. Opportunities can also be provided for students to have agency to access design technologies on and off campus using their own devices.

- eMaking requires the developing of staff capabilities and confidence to teach eMaking and to change their pedagogical approaches from teacher-directed to student-centred learning. This can be achieved through implementing professional development approaches whereby lecturers have the opportunity to share their eMaking teaching and learning experiences with other staff. This sharing can be captured and presented in multiple forms of knowledge from simple documents to video explanations that can be easily found and viewed on a range of devices. Institutions should also consider how to recognise and reward staff who are improving teaching and learning practice through the use of these technologies. Universities need to raise the importance of teaching and learning by recognising and rewarding those staff who are realising the full potential of 3D technologies.

Resources for exploring

The following organisations offer 3D printing for students. The list is not comprehensive as 3D printing is evolving at a fast pace and this list does not mean to suggest endorsement as each organisation needs to be reviewed to determine the best in terms of access requirements, cost and location.

Shapeways	Claims to make 3D printing affordable and accessible, connecting people around the world and providing access to the best technology. URL: http://www.shapeways.com
iMaterialise	Provides a range of 3D services including printing designs and access to experts. URL: http://i.materialise.com
UP3D or Makerbot	Various printers currently available. URL: http://3dprintingsystems.com/products/3d-printers/up-3d-printers-overview/ and http://www.makerbot.com/

Guides, Cases and Readings

The following resources from the *NMC Horizon Report 2014 Higher Education Edition* (Johnson, Adams-Becker, Estrada and Freeman, 2014) are recommended to further explore how 3D technologies can be used in higher education.

- Campus Makerspaces – Audrey Watters, *Hack Education*, 6 February 2013.
  URL: go.nmc.org/mspa
- Baltimore's Digital Harbour Tech Centre – Tim Conneally, *Forbes*, 18 January 2013.
  URL: go.nmc.org/timc
- Is making learning? Considerations as Education embraces the maker movements – Rafi Santo, *Empathetics: Integral Life*, 12 February, 2013.
  URL: go.nmc.org/makelea
- What is the maker movement and why should you care? – Brit Morin, *The Huffington Post*, 2 May 2013.
  URL: go.nmc.org/mamove
- 10 ways 3D printers are advancing science – Megan Treacy, *Treehugger*, 16 April 2013.
- Leading edge thinking – Kevin Cella, *UDaily*, 19 September, 2013.
  URL: go.nmc.org/ude

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