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A study of children's relationship with making and use of CAD in collaborative, informal environments and the implications for institutional learning environments

Abstract

In this paper, the researchers will investigate different ways in which school age, 'generation net' children learn, through non-linear, mediated, collaborative 'making' environments, enabled by informal club settings and online 'builder' gaming and groups. In addition to this, the study will investigate these learning methods in relation to children's future attitudes to formal education and their engagement with the ethos of open access digital fabrication facilities.

The research will draw upon primary sources including the observation and analysis of children who attend 3D printing clubs created by one of the authors. These clubs are aimed at children who are just starting their formal school education, from the age of six. The clubs are informal and relaxed to allow a great deal of creative freedom. The children have access to 3D printers, CAD software and 3D printing pens to allow them to explore the technology and design process in different ways. They can choose to work together or alone, and can participate in the group discussion in an unforced way. This research will conclude by analysing the educational benefits of informal shared design practices and digital fabrication making processes and how they could be used in the learning spaces of the future.

Making Builder Games 3D Printing Computer Aided Design Informal Spaces Learning

1. Introduction

This research examines several characteristics of the digital making process. In particular it will look at ways in which children engage and learn when given the access to these informal maker environments and tools. It will then consider how their particular way of interacting with these approaches and processes may influence current and future learning strategies, which could be applied to more formal and institutional environments.

Children, making, and what we can learn from their methods and creations, in an 'unstructured' environment is well documented, although not always put into practice in institutionalised places of learning. The idea that education should be more experiential and connected to real world objects is

originally attributed to John Dewey but also to many other scholars and innovators including Frobel, Freudenhal and Montessori. (Dewey, 1902; Freudenhal, 1973; Frobel, 1887; Montessori, 1964). Friere, (1973) introduced the idea of culturally meaningful curriculum construction, in which designers get inspiration from the local culture toward creating 'generative themes' with members of these cultures. Papert's (1980) theory of constructionism describes the importance of learning through the experience of doing.

This research, based on a case study from a digital making club set up by one of the authors, called 'Wee Replicators', observed how children naturally interact with digital technologies and how these children are informed by their experience of digital 'builder games' such as Minecraft. This research explores the relationship between digital experience of CAD (Computer Aided Design), through online interaction in shared space games, and physical CAD, through 3D printing technologies at a childrens' maker club. The children observed in this study showed a flexibility in their use of CAD and 3D printing technologies, with innovative results that could not have been achieved through a structured taught programme. Their designs and objects created were reflective of and directly inspired by their 'hobbies'. These results were then analysed alongside the existing literature on making and constructivist learning. Through this theoretical and empirical study, implications for educators and learning spaces of the future will be proposed, contributing to long standing debates around progressive versus institutionalised learning. The main aims of this study are therefore:

- To investigate how informal club settings and the devices used within them affect the outcomes of the children's' learning, designing and making experience
- To compare the children's' experience of online, hobby led activities with their learning outcomes in the digital making club setting
- To synthesise these results into outcomes that may relate to institutional environments for multi-generational learners

2. Literature Review

2.1 Digital Making, 'Connecting' [Processes and People] and Learning

There are many definitions of 'connecting'. In this study it is considered in the context of how children connect with other individuals in an informal group setting, including with their 'mentor' and peers; as well as how children connect the multifaceted processes involved in making through

different physical activities and different combinations of all these interactions. The value of this type of connecting is not always appreciated as a way of learning in institutional environments.

According to Gauntlett, (2011 : 2) '[digital] making is connecting because you have to connect things together (materials, ideas or both) to make something new; making is connecting because acts of creativity usually involve, at some point, a social dimension and connects us with other people and making is connecting because through making things and sharing them in the world, we increase our engagement and connection with our social and physical environments. These processes were all embedded, informally, into the Wee Replicator digital making clubs.

Research around making and connecting also explores the connected interaction between a sense of self, emotional expression and tangible physical outcomes. Margetts (2011 : 39) believes that 'making is a revelation of the human impulse to explore and express forms of knowledge and a range of emotions; an impulse towards knowing and feeling, which shapes human action and hence the world we create. The reward of making is the opportunity to experience an individual sense of freedom and control in the world. Making is therefore not only a fulfilment of needs, but of desires – a process whereby mind, body and imagination are integrated in the practice of thought through action.'

Looking at children in particular and the way they connect in online games, sharing their processes and 'creations' and learning is also of relevance. Gershenfeld (2005:133) said that, 'the inventiveness of children has led to a historical blurring of the distinction between toys and tools for invention, culminating in the integration of play and work in the technology for personal fabrication.' This highlights the potential of integrated learning through play for productivity and comprehension. Fox (2014:20) said, 'in workshop based third wave DIY, manual manufacturing can facilitate social learning.' By working with or in the company of others a sense of camaraderie may develop which can lead to empathy and a more meaningful shared experience. This type of learning which encourages empathy are included in informal learning environments in ways not normally considered in institutional teaching.

Resnick (2007:1) says that 'the [connected] "kindergarten approach to learning"- characterized by a spiralling cycle of Imagine, Create, Play, Share, Reflect and back to Imagine — is ideally suited to the needs of the 21st century, helping learners develop the creative-thinking skills that are critical to success and satisfaction in today's society.' This seems particularly relevant today because of the increasing dependence on the integration of technological and creative skills.

There is some criticism of integrating these skills as Davies (1997:440) discusses that encouraging maker attitudes and work ethics will produce a generation of entrepreneurial workers who are equipped for twenty first century economies. Lindtner (2016:15) questions the motivation of venture capitalists and critical scholars who are invested in the idea of making as an intervention in education. There is an anxiety of what maker education may do when it is attached to a 'neoliberal capitalist agenda'. There are two opposing groups that are advocating learning through making- those dedicated to an improvement in the inclusivity of education and those who see the entrepreneur as the most desirable future worker, who is responsible for their own conditions, pay and welfare. This scenario of two opposing interested groups is particularly evident in the way western scholars see the maker movement compared to how Chinese scholars see it. (Lindtner, 2016) However, despite the perceived possible future worker exploitation, the literature still suggests that experiential learning is more effective and inclusive and therefore it is worth exploring and researching further.

2.2 Online communities, 'builder' gaming and learning

Many children in western cultures have a particular knowledge and affinity with online making, planning, 'building' and shared visual 'commons' through games such as Minecraft. Their online sharing allows players to visit, interact with and change their friends' designs or those by celebrity 'vloggers' such as Joseph Garrett (Stampy Cat). While their Minecraft 'architectural' designs stay within the online space, how this may impact on future design education, based on children's developed understanding of processes such as CAD or digital making have yet to unfold. According to Delaney (2016 : 1) 'in Minecraft, players build their world around them by removing blocks on a regular grid. Today's children enjoy Lego, but seem far more inspired by Minecraft.' In the case of the Block by Block project, online children's communities are utilised. Discussing this, Schkolne (2016 : 2) said 'groups of young people gather for a workshop where, collectively in Minecraft, they together plan and design a space.' Going further, the community oriented creativity might impact the future of architecture as there is a growing opportunity to co-design public spaces. For those growing up co-designing and co-producing online, a effective collaborative approach to design in the real world seems a natural progression.

Combining the positive aspects of making and digital connectivity is 'digital craft', which includes 3D printing technologies. These have the ability to 'retain the soul of the material and the skill of the human hand, while also benefitting from the precision, efficiency and increasingly unrestricted structural parameters of digital design and fabrication.' (Johnson, 2014) This is particularly evident

within the Wee Replicators clubs where children particularly utilise the 3D pens, giving a fairly instant, tangible 3D outcome in combination with the use of 3D printers and CAD lessons.

Weber suggests that 'children's play flows easily on and off line, in and out of roles, weaving back and forth from the imaginative to the actual. It is in this blurring of boundaries between physical and cyberspaces, between the virtual and the actual that children create play spaces for themselves'. (Weber, 2010: 104) Increasingly this is being facilitated through affordable mobile computing (phones, tablets and pads) in which the device facilitates 'the collaborations between students' which 'transform the spaces in which students work.' (Fisher et al, 2013) This has implications not only for the way that visual design may be taught using the tools of CAD, but also the actual spaces in which engagement and learning may take place.

2.3 Children and digital technologies

Contemporary western children, with their understanding of digital and online technologies, belong to a global community often through their online gaming, in some cases even more so than the communities in their physical locale.

Despite the profusion of information and the learning and social opportunities available online, certain things cannot be taught, learned or achieved as well as they could be in a child's physical reality. These include the digital making of physical items created by 3D printers or other making technologies, often provided in open access 'Fab Labs' and 'Maker Spaces'. These are places where the public, often with the input of a 'mentor' rather than formal 'teacher', can make and realise their own designs. The types of equipment provided in these spaces can include different types of 3D printers, laser cutters, CNC routing machines and sewing machines. There are some companies who offer these making opportunities as services, including 3D Hubs, who claim that if you have a 3D file, you can upload it and it will be 3D printed and delivered to you within 48hrs. (3D hubs, 2016). However, few, if any of these services are aimed at children and most lack the learning stage that leads up to the creation of the necessary 3D file.

These maker spaces, which also often combine informal group classes with the one-off, open-to-the-public bespoke service, although primarily aimed at adults, are beginning to invite children to explore and experiment. As Dougherty (2014 : 75) explains, 'we need adults to facilitate and create maker spaces in their communities that are accessible to all children.' Once children see themselves as learners who have good ideas and can transform these ideas into reality they become empowered.

Open access digital fabrication facilities, through unstructured group and individual projects, can provide innately creative group based spaces, collaboration and imaginative problem solving, while traditional school models can emphasise uniformity and predictability. By welcoming online communities and encouraging the creation of child accessible maker spaces and groups in all local communities; the implications for technology, in the context of making and learning, can expand beyond parental concern of physical social isolation and computer dependencies. It can, potentially, replace the concept of technology as an artefact or function with the ideas of what it might facilitate on a personal and social scale. (Mizen, 2001) One of the few examples of maker spaces that combine classes for adults, after school clubs and also an integration of their practices into the curriculums of several schools are the Curiosity Gym in Mumbai. They say ‘DIY [handmade utilising digital tools] activities and processes reflect your personality. DIY is a maker culture that discovers simple processes to generate outstanding projects of great utility. It discovers the maker in you and encourages you to take up challenges to create useful objects. You can learn faster from the hands-on experience.’ (Curiosity Gym, 2017) They also offer the following graph of ‘DIY’ learning that occurs in their various classes and workshops put together from Bloom’s Taxonomy and their own observations.

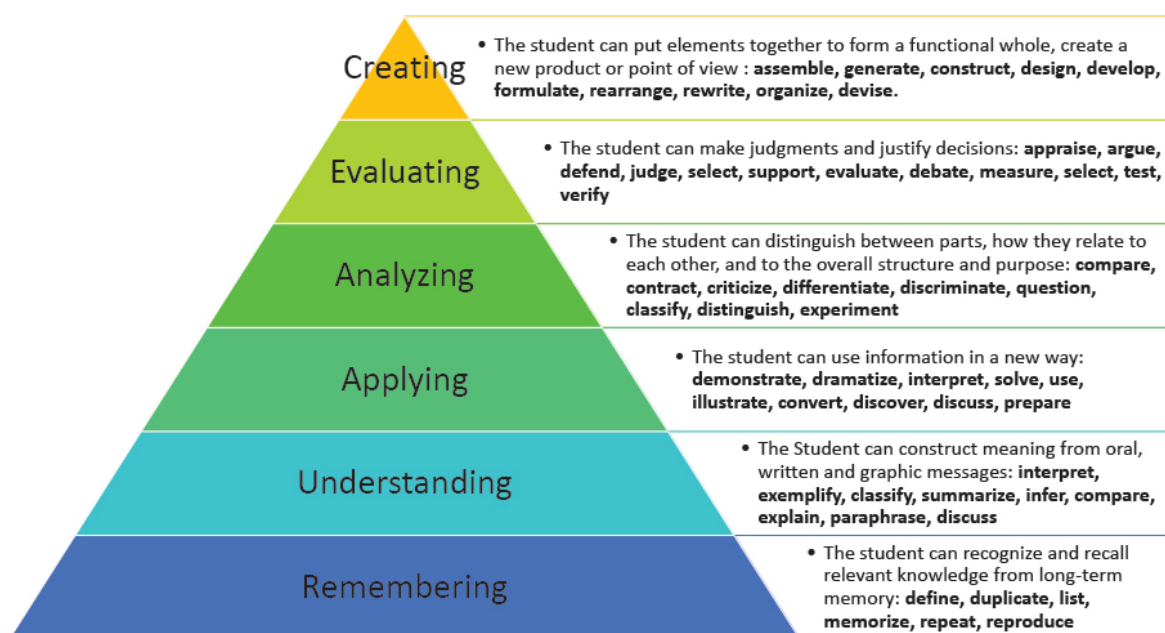


Figure 1. Taxonomy of learning at the Curiosity Gym open access maker space

Lipson and Kurman (2011) discuss ‘earl grey syndrome’ which is the problem of only being able to desire what one already knows exists and therefore not contributing to new ideas and solutions. Perhaps children can overcome this problem more easily if they grow up without having limitations put on their imagination by their understanding of what is possible. Children appear to have a fluid,

open mindedness to what can be achieved through digital, online and technology that they can easily manipulate. Their online relationships, whether they are with peers, constructed groups or with celebrity vloggers, come naturally to them and will be impactful on how information, including 'design files' created on CAD, is shared, now and in the future. Perhaps more so than with links between 'analogue' play, including adventure playgrounds, (Lambert and Pearson, 1974) wooden blocks, Montessori, (ibid) and Lego (Rogers, 2001) and measured learning outcomes, 'hobby' led digital designing and making, in informal and institutionalized settings can blend children's' real interests and skill acquisition.

3. Methodology - Observational research of children in a digital making club

A research protocol was designed and agreed with the parents of the children involved, which also adhered to Edinburgh Napier University research integrity protocols. Informed consent was given by all parents of participants for them to take part in the research and have their photos taken. The children were also spoken to and made aware that they could withdraw from the study at any time.

This research draws upon primary sources principally the observation and analysis of children who attend 3D printing clubs hosted by one of the authors, Denise Allan. These clubs are aimed at children just starting their formal school education, from the age of six. The clubs are informal and relaxed to allow a great deal of creative freedom. The children can be observed in as natural a state as possible. They have access to 3D printers, CAD software and 3D printing pens to allow them to explore the technology and design process in different ways. They can choose to work together or alone, and can participate in the group discussion in an unforced way. The clubs are regular, weekly events to ensure that the excitement and novelty of the access to these tools does not overshadow natural behaviours and obscure what can be learned about the implications for learning and open access fabrication.

The following observation was achieved by preparing, in advance, the environment and the situation. The children grew to accept Allan as part of the group and were accustomed to her taking photographs frequently. This allowed the observation to be conducted by participant observation, using photographs as field notes. By keeping the environment as normal as possible Allan was able to actively see and understand the motives of the children and keep a rigorous record of the events and behaviours as and when they occurred. (DeWalt, 2002)

This case study began with informal observations of over a hundred children that attended the workshops at the Wee Replicators 3D printing clubs, with work by two boys disseminated in this paper. These clubs provide children with access to a 3D printer, 3D printing pens and Google SketchUp modelling software. This case involves a six year old and a ten year old who, at the point

of this observation, had both been attending the 3D printing club for almost six months. This observation took place in March 2016. The boys sat down at two computers and opened up the modelling software. (See Figure 2) Neither of them had used the software before and so they were both given a quick demonstration at the same time, they were briefly shown some of the tools, which included the pencil tool, the rectangle tool and the push-pull tool. Both boys started as soon as the demonstration was over.

This particular case was chosen to represent the many occurrences of the same phenomenon as there were fewer differences between them and so conclusions could be drawn more efficiently as they were the same gender, had the same experience of 3D printing and they both had no experience of CAD.



Figure 2. The two boys using Google SketchUp

4. Primary Research Observations

The day that the case study was undertaken at the 3D printing club, there were eight children attending. Therefore, the observation was not constant and instead, the boys were observed every 5-10 minutes for a few minutes. Approximately 10 minutes after starting, the six year old shouted for help. It was not possible to help him immediately as other children needed attention. Therefore, it was about 5 minutes before he could get assistance but by that time he had already worked out how

to fix the problem he was having. The problem he had was that when he was using the push-pull tool, the shape was not solid and appeared to be hollow. The software highlights this by making the object light blue instead of grey. The six year old had recognized this as a problem and worked out how to fix it.

Conversely, when viewing the work of the ten year old, it was clear that he had the same problem (see Figure 3). Instead of stopping and trying to fix it, he had carried on, ignoring the issue which at that time was starting to cause him problems. He had a Lego figure next to the laptop and was clearly copying the structure but making it the shape of what might be thought of as a traditional robot. As he had not fixed the push-pull problem, he was having difficulties making the indents in the feet of the robot so that it would click onto Lego bricks. The six year old had drawn a series of blocks pulled out from one another, (see Figure 4). He said that it was, 'a house from the future'. He was asked if that is what he was making from the beginning and he replied, 'No, it just turned into a house.'

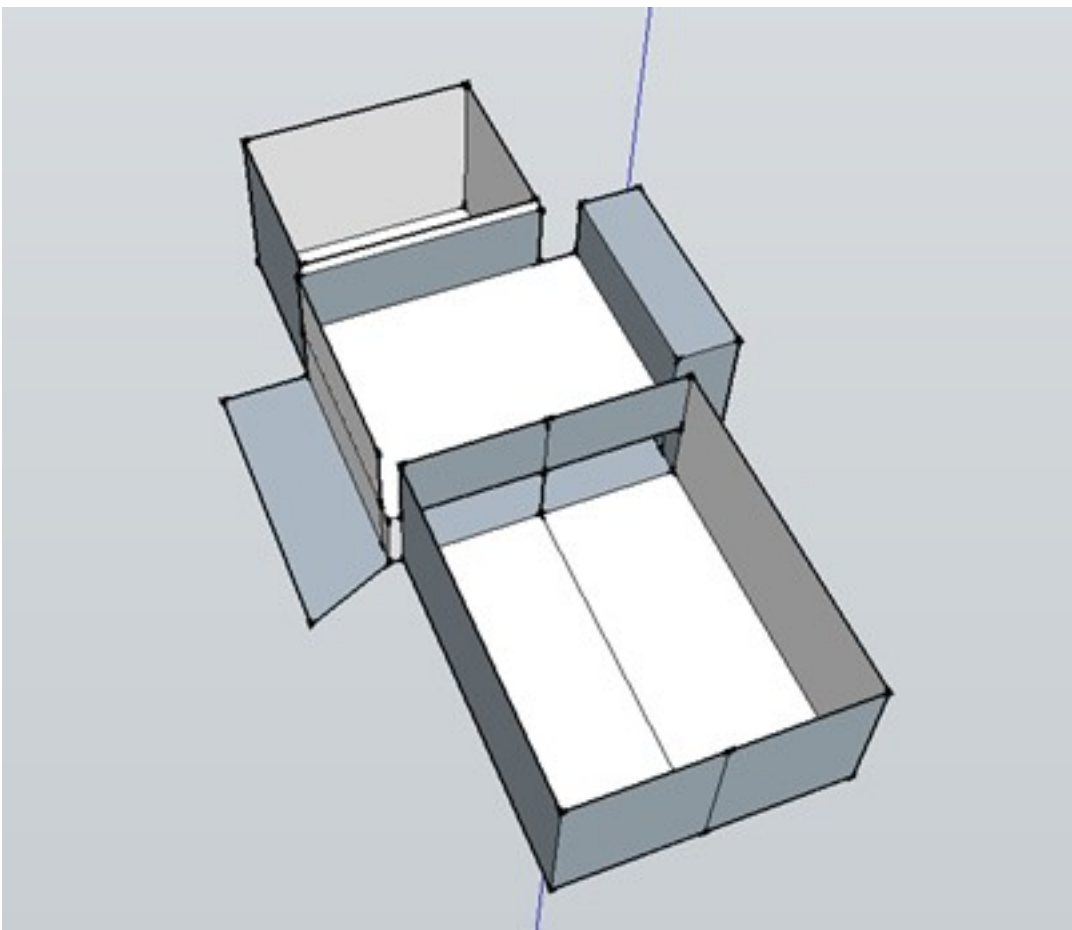


Figure 3. Ten year old's robot model was not solid due to problems with the push-pull tool.

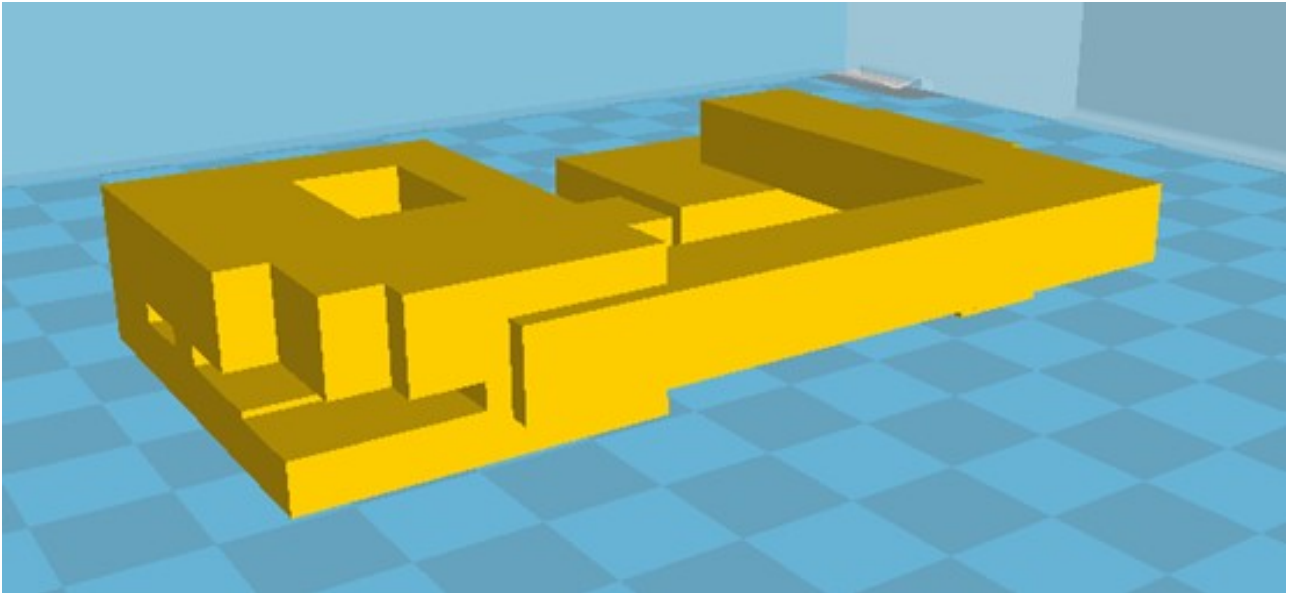


Figure 4. The six year old's model was constructed using rectangles pulled in and out of other rectangles.

Both boys were familiar with 3D printing and the process to prepare a model for printing. The six year old asked that his 'house from the future' be printed with supports so that it would, 'have the stringy up and down bits', which he liked the look of on other items he had seen printed. The boys saved their CAD drawings and asked for them to be printed in time for the next 3D printing club. The six year old's model was printed as he left it, as it required no alterations. The ten year old's model required significant changes in order for it to be 3D printed, (see Figure 5).



Figure 5. Final model of the ten year old's robot.

5. Findings

Learning about CAD can sometimes be a repetitive, drawn out process. Traditional design education in Scotland, in a formal context generally starts in 3rd year of secondary school when students are approximately 14 years old. Through the personal experience of the author, it seems that to learn both technical drawing and CAD skills in school and university, students are generally set a project to copy an existing design. (Solidworks, 2016) Through copying products students are able to see and feel what the object feels like and from an educational point of view, educators can pick objects, which ensure students learn key skills such as fillets (how to round edges and corners of a model). This appears to be a legitimate learning technique and has proved to be successful, although not necessarily enjoyable.

Considering this case, perhaps while learning CAD children should be encouraged to explore the tools available and try them out, and not be encouraged to replicate an existing product. The child, who experimented with the tools without a particular object in mind, was able to successfully create an aesthetically pleasing model, (see Figure 6) Alternatively, the child who attempted to copy a Lego figure created a model that looked recognizable, but it was not viable as a 3D printable object.

This observation is supported by the concept that learning by copying or from a book is not always as successful as learning by experience. When learning through experience, the learning is more memorable and connected as the person had to act off his/her own accord to achieve an outcome instead of merely reading or copying a method. (Jakubowski, 2003) However, this method may only be applicable for children and or beginners for a short time. If they are to go beyond basic CAD skills they will likely have to take a more structured approach to learning specific skills in order to achieve a particular task. However, this can still be achieved in a constructivist way. (Thirteen, 2016)

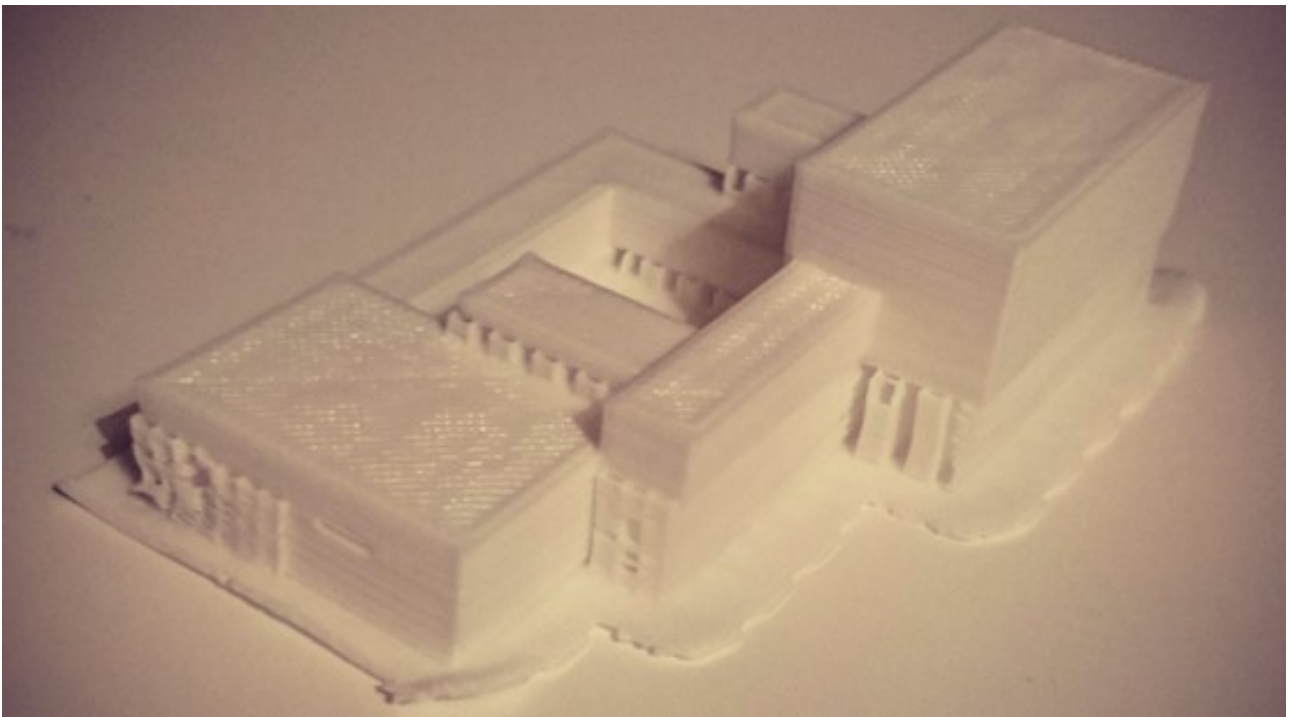


Figure 6. Final printed model of the six year old's 'house from the future' including the support material that he wanted to leave on the model.

In terms of problem solving, the child who experimented was able to solve his problem when help was not immediately available. He had no particular goal in mind and so was able to go backwards to try something else. However, the ten year old was focused on creating a robot and when he came upon the same problem, instead of stopping to fix it, he carried on making his robot, perhaps thinking that he would fix the problem when he was finished. This illustrates the idea that experimentation is a legitimate method for problem solving as it encourages an iterative process which allows a person to repeat a task as many times as necessary to achieve the desired result. This can be likened to the theory of multiple-try feedback. This is a system often used in mathematics, where children are given the opportunity to answer a question or problem until they get the correct answer. It can also be likened to the serendipitous aspects of traditional craft. This differs from a

multiple-choice method of learning. During the processes outlined in this study, children are provided with the opportunity to find the correct answer or solution for him or herself, and not to simply be told what the right answer or solution is. In addition to this, they are not given a selection of possible correct answers or solutions, allowing their solutions to be more innovative. (Attali et al. 2016; Rossella et al. 2014) This also often takes place in ‘builder’ gaming situations when breaking down ‘built’ structures can be easily reconstructed without there being any repercussions. By discovering how best to facilitate and encourage the learning of CAD skills at a young age, fabrication tools will have a far greater opportunity to be culturally significant, democratized and to become open source on a wider scale.

Conclusions

By analysing the educational benefits of informal shared design practices and digital fabrication method, they may be seen as tools to be used in more institutionalised learning environments of the future. Digital making and informal learning environments have been shown to be a positive influence on the innovative outcomes of the participants in this study and reviewed in the literature.

This study aimed to investigate how informal club settings and the devices used within them affect the outcomes of the children’s’ learning, designing and making experience. In doing this, the case study showed that children who explored maker tools without a particular objective had a more successful learning experience as they found solutions to problems as they played, whereas the children who had an end point in mind tried to get there while ignoring the problems they had encountered. The learning which occurred extended beyond the skill to use a particular tool but also included the ability to persevere, communicate with peers and mentors while also picking up other core skills such as spacial awareness, measuring, adding and subtracting. The informal club setting lends itself well to this type of learning as it is extracurricular and therefore not constrained by the learning targets placed on institutional facilities. However, perhaps with more research and substantiated evidence educational policy makers will trust that targeted learning objectives are achievable using informal learning strategies such as those described in this paper.

The study also considered the similarities and differences between how children use and are frequent participants in online virtual maker environments such as Minecraft and how they played and participated in digital making clubs with access to digital making technologies such as 3D printers. One of the most obvious outcomes of children being part of online maker communities was their perseverance to keep trying until they achieved their desired outcome. In the digital spaces online children can easily press undo until they manage to do what they intend to. This ability to

start again as many times as necessary has led to a perseverance which has moved into real world maker-spaces too as children seem to trust that they will get 'it' eventually. In the case discussed in this paper one child utilised the 'undo' function to effectively find solutions while the other assumed that there would be a solution and did not worry that his model temporarily did not look right. Although the first child displayed the desirable learning through exploration, the second child demonstrated a trust in their ability to make it work, whereas children who are not part of online maker games may have given up when it started to go wrong. Additionally, although not specifically discussed in this case study, online maker gaming has resulted in children who effortlessly collaborate with others and see co-design and co-production as the way that design and making happens. This is evident throughout the digital making clubs run by 'Wee Replicators' as children work together, help each other and give each other advice without hesitation.

The intention of this research was to provide some preliminary outcomes which could be used in institutional education environments. Therefore the following guidelines have been developed from the findings:

1. Allow students to spend time exploring the topic of their lessons to allow them to see connections and make the subject relevant to their interests and hobbies which will make their learning more personal and meaningful to them.
2. Give students the freedom to use digital technology and maker tools for their own personal projects. This builds passion and responsibility in students making them feel capable and valuable.
3. When a child comes up against a problem avoid giving them the solution. Instead support and encourage them to find solutions for themselves.

The open-access aspect of maker spaces, that brings together diverse online and physical communities, is also worthy of further investigation. Gershenfeld (2012 : 51) said, 'Fab Labs seek to balance the decentralized enthusiasm of the do-it -yourself maker movement [the online community of enthusiasts for this subject] and the mentorship that comes from doing it together. After all, the real strength of a Fab Lab is not technical; it is social. The innovative people that drive a knowledge economy share a common trait, by definition, they are not good at following rules. To be able to invent, people need to question assumptions. They need to study and work in environments where it is safe to do that.'

Other studies have had noticable outcomes with Blikstein concluding that 'digital fabrication and 'making' could be a new and major chapter in this process of bringing powerful ideas, literacies and expressive tools to children'. (2013 : 2) 'Creative prototyping, shared creativity and the supportive underlying infrastructure play an essential role in the motivation of children and novice users'. (Posch et al, 2010 : 257) From research gathered to date, the skills all users may acquire through their interaction with the informal learning through digital making technologies include team work, research skills, communication skills, design thinking, technical drawing skills, entrepreneurial skills, computer skills, creativity, innovation and cooperative learning, all in a place that is 'different' from traditional learning environments. Observations of online 'creative' communities, maker spaces and informal learning environments for children, including those created by Allan and online children's' community projects such as Block by Block, show that a great deal can be learned from the innovations that occur there. While constructivist teaching, informal learning in unstructured environments originated with Dewey et al, online and digital making technologies, integrated with these approaches, offers real opportunities to develop and enrich education and wider society.

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