3D printing education as a means of building confidence and preparing children for skills considered necessary for the 21st Century: A grounded theory study verified by empirical research.

Volume 1

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Declaration

I confirm that this thesis is the result of my own, independent work and that it has not been submitted for any other degree or professional qualification.

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Abstract

This thesis aims to demonstrate childrens' engagement with 3D printing technologies in 3D printing workshops through a large study of children. This will provide qualitative and empirical evidence which supports the benefits of making for children and advocates the use of 3D printing technologies within educational settings.

This thesis challenges the common narrative that making is a fundamental human trait. It proposes that making should be understood on a spectrum between making for necessity and making for leisure. This illustrates the diversity of experiences making offers. It provides a thorough and informed perspective on how 3D printing can be used successfully in project-based learning within classroom settings.

The study presents empirical data from 3011 participants across 247 workshops and shows which reported behaviours are common to all 3D printing workshops. Further, this study demonstrates the impact the workshop environment has on these behaviours. Additionally, the analysed data shows that motivations for making can be categorised as social-based or learning-based. This provides maker-spaces with an alternative perspective of the motivations to participate in making and to promote access.

This thesis presents the first empirical study of children and making and is also the largest known study at time of writing related to this field. It offers an alternative interpretation of maker practices to make making more inclusive and presents evidence that 3D printing pens are valuable tools for introducing children to 3D printing. Furthermore, a sample lesson plan is included in the appendix which highlights how 3D printing can be successfully included in the classroom. Finally, proposes, using empirical data, that 3D printing workshops develop skills considered essential for 21st Century learners.

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Definition of key terms:

3D printer: A 3D printer is a machine which creates a physical three-dimensional model from a digital file. The printer extrudes a material, in most cases a type of plastic, and lays the plastic down on a glass bed in layers to construct a solid model.

3D printing pen: A portable hand-held machine which extrudes a material, in most cases a type of plastic, and is operated by the hand of the user (See Figures 30-35)

Art :Art is the ability to create something which betrays a feeling. The end result does not have to be or look well made. It is solely about the feeling it emits. The boundaries of art lie within the artists ability or willingness to recognise their output as art.

Craft: Craft is the ability to make something which is and looks well made. The end product is usually created by following instructions or a pre-determined process. The boundaries of craft are determined by how closely the crafter follows the pre-determined process. Previous experience of engaging in the craft can determine how successful the end product will be.

Making: Making is the creation or repair of something by intuition. This may be done alongside some instruction but will rely largely on intuition, feeling and past experience to achieve the desired result. When making, a finished or working end result is not always necessary as the activity does not need to have a fixed end point. The activity relies on the experience of the process. The boundaries of making lie within the maker's intention and the process taken to make.

Introduction

Overview

Making is an activity that humans have participated in for as long as they have existed (Hatch, 2014:16). However, in the last 15 years making for leisure has grown in popularity. Many people identify as makers and report benefits of improved well-being, awareness of personal agency and skills to do and make things that make them happy (Ibid). This thesis presents a study conducted on the fringes of 'The Maker Movement'. 247 workshops in the central belt of Scotland with 3011 participants have provided digital fabrication tools, namely 3D printers and 3D printing pens to children and young people.

Literature on 'The Maker Movement' focuses largely on the use of making by adults, though some studies have explored how making can be used in schools with children (Thomas, 2014; Chu et al., 2015; Papavlasopoulou et al., 2016). The current literature largely overlooks the debate on equity of access to making for leisure. It posits that making is an activity that everyone has access to and is inclined to do at some point in their lives (Hatch, 2014: 1). There has been a recent increase in the number of maker-spaces (Anderson, 2013), which indicates an improved accessibility to the tools of digital fabrication. These are spaces where people go with the intention of making. However, this study acknowledges the value and potential associated benefits of making in non-traditional digital-making environments. The findings demonstrate that the benefits of making are not restricted to those engaging with the objective to make but can be available to those engaged in the process of making, with or without an objective. This is evidenced in this thesis when 3D printers (a maker-space tool) were taken into childrens' social spaces, which showed that the benefits of making are shared, regardless of the motivation to participate.

Aims of thesis

This thesis is atypical in that there were no defined research questions at the outset of the research process. The topic was described loosely as 'children and making'. Prior to beginning this PhD, the author of this thesis started a business and social enterprise which aimed to give children and young people access to tools of digital fabrication. She wanted to give as many children as possible the opportunity to witness their own capacity by providing them with tools they could use to make things that they would be proud of. This initiative has grown over the past five years and the social enterprise is now run from premises in Edinburgh and employs staff to run workshops and classes for children in the surrounding areas.

This study was inspired by experiences and anecdotal observations of children in a digital making environment. Additionally, the author is contracted by several organisations to teach 3D printing in schools. She also provides maker-empowerment sessions with children in hospital and mental health wards. In the same capacity, the author is working with charities to facilitate relationships between different generations and cultures to overcome social challenges, using 3D printing as an activity to bond over. While running the first workshops, the author noticed that some children experienced a transformation in their confidence and self-esteem, while others demonstrated significant perseverance when trying to get their models to work. This prompted the conceptualisation of this study. It aimed simply to observe 3D printing workshops and explore common behaviours. It collected qualitative data in an attempt to evaluate why these behaviours were exhibited and to understand the significance of 3D printing as a maker activity. Due to the many workshops that the author personally delivers every week, there was a considerable number of opportunities to observe and analyse behaviours. This makes it the largest known study based on maker activities with children.

Brief review of literature

The review of literature was conducted after the data was collected and analysed. This is consistent with grounded theory methodology, as outlined by Charmaz (2013). She recommends that theoretical sensitivity is maintained by only reviewing literature after the data has been analysed. This ensures that awareness of the findings of others does not influence the interpretation of the data in this study.

Literature was reviewed in response to the findings of this research. The following areas were used to contextualise this thesis: art, craft and making, ‘The Maker Movement’, making and Children, 3D printing pens, 21st Century skills, common theories of power and implication of autonomy.

Art, craft and making was explored in terms of how people relate to it. The studies of notable researchers were reviewed including Titus and Synacore (2013) and Reynolds (1997) who discuss the associated benefits of engaging in arts-based activities.

Research on the 'The Maker Movement' was reviewed to situate maker practices within the making sub-culture. Works reviewed for this purpose included Gershenfeld (2007), Peppler et al. (2016) and Eisenberg (2013) among others who discuss what 'The Maker Movement' is and how and why people participate. The study of making in relation to children was considered specifically to identify the distinction of the affordances that making offers children compared to adults. Notable texts and research on this included Leadbeater (2009) and Hung et al. (2019).

The use of 3D printing pens recorded within academic literature was analysed. It revealed largely sceptical attitudes towards 3D printing pens and a limited concept of what they could be used for. A discussion about the skills considered essential for 21st Century learners is also presented. Notions of which skills are necessary was highlighted in research by Wagner (2008), Hanover Research (2011) and The Harvard Advanced Leadership Initiative (2014).

Finally, common theories of power were identified to consider what impact empowerment of an individual can have and how power is considered among the power-less and the power-full. For this purpose, works reviewed included Foucault (1976) and Dore (2010). This provided a basis on which to consider and challenge the implication of autonomy for children. This was contextualised through the work on autonomy by Christman (2009) and autonomy supportive environments by Van Der Kaap-Deeder et al. (2016).

Scope of study

The qualitative data collected for this study included the observation of 247 workshops. As such, there were many strands of inquiry which extended beyond the scope of this study. Therefore, the points of inquiry explored were those most prominent within the data. There are two stages to the research presented within this study. The first stage provided qualitative data, which was used to design a verification study to collect quantitative data for the second stage of this research. The verification study checked for the occurrence of the findings in stage 1 of the research. More details regarding this can be found in Chapter 3. The study is based on observations of workshop participation by children and young people between the ages of 3-18 with the median age range of 8-11. The workshops discussed took place in the central belt of Scotland. Only two workshops were conducted outwith 20 miles of Edinburgh. The overall study refers to making as part of 'The Maker Movement'. However, the tools used in the observed workshops included an Ultimaker 2 3D printer, generic brand 3D printing pens and laptops with Google SketchUp computer-aided design (CAD) software installed. The observed workshops in stage 1 of the research took place between May 2016 and November 2017. The observed workshops in stage 2 of the research took place between July 2019 and September 2019.

As the study was directed by the data collected and the line of analysis was not predetermined by a research question, the scope of this study extends from 'The Maker Movement' to educational theories and democratic access to the arts.

Critical evaluation of current state of literature

As 'The Maker Movement' emerged just 15 years ago (Dougherty, in Thomas, 2014) the literature available on making is limited. There is a necessary reliance on a small number of keys texts (Gershenfeld, 2007; Anderson, 2013; Hatch, 2014). These texts argue that: 'making is fundamental to being human' (Ibid: 1). Further, Dougherty (2016) discusses making as an opportunity to bring people together, whilst Gauntlett (2016) proposes that bringing people together can cultivate social capital. Additionally, several researchers (Papavlasopoulou et al., 2016; Ford & Minshall, 2019) communicate the need for more empirical studies on making so that the benefits and potential can be better expressed, and extrapolations can be made to other scenarios.

There are many studies based on observational work and autoethnography, which provide a deep insight into specific maker practices (Nemorin, 2016; Nemorin &

Selwyn, 2017). However, with regards to children there are no known empirical studies about making and children. Without empirical data to contextualise or situate observational or autoethnographical work the research is vulnerable to being unnoticed or even viewed with scepticism.

Additionally, there is little evidence in the literature describing the use of making in primary schools. This does not mean that it is not happening but highlights a lack of practice-led discourse in this field. This demonstrates the value of filling this gap with empirical evidence. However, teachers who do publish research about making in the classroom express concern at the lack of pedagogical framework for 3D printing in schools (Song, 2018).

Empowerment is often cited as a benefit of making (Thomas, 2014; Gauntlett, 2016). However, when applied to children, empowerment must be supported to ensure that children positively experience this newly acquired power and are not negatively affected by it. Within maker literature the empowerment of children is viewed uncritically as a positive attribute without consideration of a support framework required to facilitate this empowerment (Gershenfeld, 2007: 254; Thomas, 2014:110).

Additionally, through instances of children taking risks and challenging rules the implications of autonomy for children were discussed in this study to propose a conceptual framework on which to understand and support the development of autonomy in children.

Furthermore, art practices are often quoted as being beneficial to participants in both anecdotal advocation as well as studies (Titus & Synacore, 2013; Reynolds, 1997). However, there is little indication regarding the individual's inclination to participate in art practices prior to the observations or studies. This poses the questions of whether there is a relationship between the inclination to participate and the success of participation, which is explored in this thesis.

As a contemporary research field, making and maker-based learning would benefit from additional studies and data to support and grow propositions and potential extrapolations. Additionally, empirical data may substantiate or challenge key propositions.

Importance of this research and its contribution

This thesis is an important addition to the existing knowledge about children and making as it challenges key theoretical propositions which have become accepted due to a limited amount of data. It also provides alternative perspectives on maker practice and provides data in the appendix adding to the available data.

This thesis presents the first known empirical study of making and children. It supports the preceding observational data and provides a basis on which propositions regarding making can be challenged. This is also the largest known study relating to children and making which adds to the data available and may legitimise extrapolations. Through propositions grounded in the data his thesis challenges key concepts of making to highlight idiosyncrasies within the making process and proposes an alternative perspective regarding the motivation for participation.

Furthermore, this thesis advocates the 3D printing pen as a tool of equal importance to 3D printers within a primary school educational context. Further, it advocates a flexible mindset regarding tools which are viewed as less important, to identify opportunities where these tools can work particularly well.

As highlighted above there was concern expressed within the literature (Song, 2018) regarding the lack of pedagogical framework for using 3D printers in the classroom. An expanded pedagogical framework was out-with the scope of this study. However, a sample 12-week lesson plan has been provided in appendix 7 informed by the data of this thesis to show how 3D printers can be introduced and used successfully within a classroom environment.

Finally, this thesis presents qualitative and empirical data, proposing that 3D printing workshops can support the development of skills considered essential for the 21st Century. This positions making as a facilitator of successful contemporary learning.

Epistemological and ontological position

The study and analysis of the data presented within this thesis is based upon the notion that factual statements about the observed phenomenon can be derived or induced from empirical observations and studies. Although the analysis in this thesis adopts this approach, the researcher is aware of the challenge to such positivist principles raised by theories of social constructivism.

The interpretation of Grounded Theory for this research attempts to bridge the gap between a radical social constructivist approach and a desire for studies and the application of knowledge to be grounded in verifiable and falsifiable observation in line with the scientific method.

This research is interdisciplinary but falls within the field of design research. Redström (2017) highlights the lack of research tradition within design and therefore cautions against a traditional approach to research. Additionally, the phenomenon being researched, 'Making' is contemporary in terms of it being viewed and positioned as a leisure activity. This has necessitated the extrapolations from other areas of inquiry. This means that key propositions are unchallenged and unevidenced within the literature. It is therefore appropriate for research to be conducted using an explorative approach which Grounded Theory offers. However, the author of this thesis recognises the authenticity of verifiable research and as such the study was conducted in two stages, a stage of exploration and a stage of verification.

Research questions and problems

The research presented in this thesis was underpinned by the data collected, rather than informed through the literature or by testing a hypothesis. However, answers were provided to fill gaps retrospectively identified in the literature and address the following questions:

1. What are the motivations for non-makers taking part in making for leisure?
2. How can the published studies regarding the reality of 3D printing in classrooms be challenged?
3. What is the value of a 3D printing pen in relation to other tools of digital fabrication?

4. Can an awareness and understanding of scales of risk and autonomy be developed in children through making?
5. Does maker education provide the opportunity for children and young people to develop skills deemed necessary for 21st century learners?

The problem identified through the review of literature conducted after data collection and analysis was the unverified findings of other studies based on children and making. Without empirical data, preceding research on making and children relies on consistency of observations across studies rather than verified findings. This thesis presents an initial verification of findings across many studies and challenges notions extrapolated from other contexts.

Important concepts and variables

The empirical data collected and analysed in this study allowed for the analysis of different types of 3D printing workshop. These were defined as Types A, B, C and D and covered children and young people from all backgrounds of society. Statistical analysis was carried out on the observations of 3D printing workshops and behavioural occurrences within the workshops to provide an overview of which behaviours and skills development can be expected when using 3D printing technologies in which type of groups.

Methodology

The study uses a grounded theory methodology which accounts for the latent literature review. Workshops were observed and documented using field notes and diary entries. These were then coded, and relevant events noted were considered. These were then condensed into more substantiated 'potential categories'. The initial data was then re-coded using the identified 'potential categories' and the most prevalent of these became 'categories' used to design a verification study. The verification study involved the facilitation of an additional 40 workshops where the identified 'categories' were recorded on a tally-checklist. The data from the verification study was then analysed in terms of observed correlations. Statistical analysis was then carried out on the verification research results to highlight differences in observations between workshop types. This methodology was appropriate as it provided the opportunity for explorative research as well as the means to verify the exploration using empirical data.

Main findings

1. **There are two key drivers for participation in making for leisure**

The findings of this thesis propose that there are two key motivations for participation in making. These are (1) to learn a new skill or (2) to socialise with like-minded people. The identification of these drivers clarifies a means to promote making to those without experience of making for leisure. This offers a resolution to the lack of discourse on the equity of making.

2. **3D printing pens offers a low-cost, access point to 'The Maker Movement'**

This study used 3D printing pens alongside 3D printers. It found that they allowed participants to create prototypes quickly and produce something to take home providing them with a physical manifestation of their capacity.

3. **Successful implementation of 3D printing**

The literature describes use of 3D printing in classrooms as inadequate due to the limitations of the technology. However, the findings of this thesis provide methods of overcoming these limitations. This includes the use of 3D printing pens for prototyping, the provision of guides to engage focus and an explorative approach to learning CAD.

4. **Making provides autonomous supportive environments**

There were several instances where participants challenged boundaries. This highlighted the responsibility that teachers and maker facilitators have to support the autonomy development of children.

5. **Skills acquired through making correspond to skills required for learning in 21st century**

This thesis proposes that skills important for learning in the 21st century, identified by The Harvard Advanced Leadership Initiative (2014) correspond to those cultivated in informal maker-based learning environments.

Layout of the thesis

This thesis will begin with a short chapter which provides an overview of existing knowledge held by the researcher. This acknowledges the core positivist concepts and values upon which, the theoretical and observed knowledge from this study is constructed. A methodology chapter, which explain the interpretation of Grounded Theory will follow. After this, Chapter 3 explains the methods employed to conduct the research. Chapter 4 presents the data collected and the codes and categories identified. Chapter 5 explains how these were used to design a verification study before discussing the results of this and presenting 'soft' theories based on this. A full review of literature will then be provided in Chapter 6, which aims to contextualise the findings. Next Chapter 7 contains a discussion of some of the findings in the context of existing research. Following on from this, Chapter 8 provides a visual summary of this thesis to offer clarity on some of the observations described. Finally, this thesis will end with a conclusion and note of recommendations for further research.

Chapter 1

1.1 Overview

Broadly, this thesis seeks to understand what happens when children are given digital fabrication tools with the freedom to make what they want. Grounded Theory will be used to develop theories from a large data set which includes several hundred workshop observations. A literature review will be carried out after the research has been conducted and analysed in order to prevent the findings of other studies from influencing interpretations of the observations or data. However, in an effort to be fully transparent, a short contextual overview will be provided in this chapter. This will outline some broad themes and concepts the researcher is already familiar with, which are assumed to be relevant to the study. These are assumed to be relevant because the study makes use of 3D printing technologies, which are considered tools of 'The Maker Movement' (Gershenfeld, 2007: 103). Therefore, an overview of existing knowledge regarding this will be provided. The study is based within informal and formal education settings and so it is appropriate to provide an overview of familiar educational theories. Making is recognised as being empowering[1] (Ibid: 254) and so the awareness of power theory will be considered. The purpose of providing this is to make clear any potential bias that may exist with regards to how the data will be interpreted. It will also provide the positivist values on which the social observations and learning will be constructed.

This chapter will first explain how this thesis will be structured before giving a short contextual basis for the study and finally there will be a short note on the intended research contributions.

1.2 Structure of thesis

The use of Grounded Theory as a methodology means that the structure of this thesis will be non-conventional. In order to allow theories and key concepts to be

[1] In this context 'empowering' is interpreted as the state in which an individual recognises their capacity to make change.

developed from the data it is important to maintain theoretical sensitivity. As such a formal literature review was not carried out until the data had been analysed. This reduced the likelihood that the data would be influenced by existing research.
The research carried out was prompted by anecdotal observations by the researcher in her existing work and will not test any pre-existing theories. The researcher was interested in how children used and responded to tools of digital fabrication and wanted to explore whether this behaviour was common when using these tools or if it was limited solely to a particular group. This is the premise of this thesis.

Due to this non-conventional structure, an explanation of the contextual basis of this study will follow this section. It aims to give a broad overview of the concepts and themes with which the researcher is already familiar. This was thought to be relevant to the study because they relate to each key element of this study: a movement surrounding digital fabrication tools, well known educational theories and an understanding of power theory. This will help to ensure that prior knowledge is declared to avoid unintentional bias in the interpretation of the data. There will then be a short section outlining the intended research contributions.

This will be followed by a chapter about the methodology, which will primarily discuss Grounded Theory, why it is appropriate for this research and how it will be applied.

The next chapter will discuss the methods used to observe and collect data. This chapter will explain the stages of research and why each method was used at each stage. There will also be a note on ethical approval procedures.

The following chapter will discuss the data collected. Due to the vast number of observations it was necessary to draw boundaries within it to decide what to take forward for analysis. A substantial volume of data was out-with the scope of this thesis and was thus discarded. This chapter will explain each stage of research conducted and how the most prevalent themes and concepts were taken forward for interpretation.

The next chapter will describe the findings of the study to this point and offer initial suggestions of what the findings mean and what 'soft' theories[2] were generated. Due to the non-conventional data collection method used, confirmation research was carried out. This was intended to confirm the findings using a more traditional research methodology. This will then be briefly explained in advance of the discussion.

At this point in the research, the qualitative data was analysed, and soft conclusions were drawn. It was therefore an appropriate point to carry out a literature review. This considered existing research in the relevant areas and provided a basis on which the study findings could be considered in context alongside existing research.

After the completion of a review of literature there will be a discussion which considers the study data alongside existing research. Finally, there will be a section which offers the final generated theories of this study. These will be constructed using the data but will be supported by the findings of existing research.

At this stage there will be a visual summary chapter which provides photographs from the research conducted to help illustrate the observations and findings described.

There will then be a conclusion which provides a summary of this thesis. This thesis will be accompanied by an appendix which will include the written diary entries for 148 workshops alongside other relevant information which is not included within the thesis.

1.3 Contextual basis of study

As discussed above, this section will provide an overview of broad ideas and concepts which the researcher feels are relevant to the study. This is not intended as a review of literature (see Chapter 6 for this) but as a declaration of prior knowledge

[2] Soft theory is the term used by the author of this thesis to describe the meaning of propositions which appear to be supported by initial observation prior to detailed analysis.

to ensure there is as little bias as possible in the interpretation of the data collected. This study is largely based around children and their use of digital fabrication tools and as such the themes assumed to be relevant include 'The Maker Movement', educational theorists, and constructs of power. These themes will be introduced below, providing an overview of prior knowledge.

1.4 The Maker Movement

Digital fabrication tools are central to this thesis and as such it is important to discuss the developing culture which has led to the widespread adoption of these. Roots of 'The Maker Movement' can be found in the DIY culture of the periods, which followed the First and Second World Wars (Frayling, 2011; Hackney, 2013). People have always made and mended things, it is 'fundamental to what it means to be human' (Hatch, 2014: 1) However, the first generation born after the First World War and then again after the Second World War had the 'make do and mend' attitude necessary in post war time after the imposed rations and shortages had been relieved (Hackney, 2013: 170). This led to a feeling of satisfaction in the experience of making and mending things (Thomas, 2014:116) . In the late 80s there was a computer revolution which saw businesses and homes transformed by the possibilities afforded by this newly accessible technology. There was a move away from making physical things as people grew more dependent on the power of computers (Anderson, 2013: 54). However, in 2005 Make magazine was launched and the first Maker Faire was held in 2006. There was a growing enthusiasm for making (Dougherty, foreword in Thomas, 2014: vii). Since the mass adoption of computer technologies, it was now possible for tools of the DIY movement to be integrated with computers to produce new, smart tools of production which allowed non-professionals to make things which looked and worked as well as manufactured goods, but without the need to mass produce items. These tools include 3D printers, laser cutters, CNC machines and vinyl cutters (Dougherty, 2013: 75).

It was now possible for people from all ages, backgrounds and levels of expertise to make a large variety of objects, which could be for necessity or decorative purposes. However, the impact that making has on those making is twofold. Firstly, knowing that one has the capacity to make whatever they want to, is significant in terms of self-worth and how one sees oneself as will be indicated below. Secondly, participating in the act of making can have many benefits which engage, delight and create a feeling of fulfilment in each individual maker (Thomas, 2014: 110).

There is a widespread acknowledgement that making things inspires and engages learners (Hatch, 2014: 20; Thomas, 2014: 12). This concurs with the theories of Piaget, which will be discussed further below. He posits that learning is deemed to be more successful and long-lasting if learners have the opportunity to create and see evidence of what they are learning (Piaget, 1976: 11-12). Making provides a space for this to happen.

Another benefit of making which is less tangible, but no less evident in literature is that making is fulfilling; it provides a type of freedom (Anderson, 2013). There appears to be a consensus that engaging in the making process feels good and can positively impact mental well-being. Additionally, failure is another aspect of making which, perhaps unexpectedly, can have significantly positive effects on the development of one's self-worth. Failure happens regularly while making and is an acknowledged part of the making process. As such, response to failure in this environment can be far more positive and productive than elsewhere. This can lead to a resilience and developed ability to be able to positively respond to failure in other situations (Hatch, 2014: 22; Lipson & Kurman, 2013: 156).

The Maker Movement will be discussed more broadly in Chapter 6. However, this short introduction should be taken as acknowledgement that the researcher is aware and informed of the movement and behaviours and ideas associated with it.

1.5 Maker mindset

Much of the literature on 'The Maker Movement' refers to the maker mindset. However, the meaning of this is implied rather than made explicit. Bruan (2015) explains that 'The Maker Movement' is not about the physical tools but rather about the learning and innovation that takes place. Maxwell (2015) says that it is her job as the librarian to ensure that academic achievement is in line with the maker mindset by providing opportunities for making. Chu et al. (2015) implies that the maker mindset is the group of characteristics developed in the process of making. Lensing and Friedhoff (2018) describe the maker mindset as having potential to increase innovation and help people stay competitive in the market. Osborne (2019) explains that she is developing a maker mindset through her work with high school students. She situates this as a response to the key commitment made by the 'National School for Library Standards for Learners' to allow students to 'Discover and innovate in a growth mindset developed through experience and reflection'. This reference to the maker mindset and growth mindset in the same context offers the opportunity to provide an explicit definition for what the maker mindset is.

Dweck (2015) defines a growth mindset as the attitude where,

> 'people believe that their most basic abilities can be developed through dedication and hard work- brains and talent are just a starting point. This view creates a love of learning and resilience that is essential for great accomplishment'.

This definition is reminiscent of the characteristics of makers as described in literature. Dougherty (2013) says that makers are aware of what they can do and what they can learn, to achieve their goals. He references the work of Dweck (2006) and agrees that her map of a growth mindset matches the mindset of a maker. This provides a clear framework on which to understand the maker mindset. It is an attitude developed through experience of problem solving, failure, persistence and success which allows the individual to witness their own capacity for learning and achieving. When an individual becomes aware of their capacity, they can apply that self-belief and confidence in other contexts which allows them to be more flexible and ready to adjust in order to positively respond to issues that they face.

1.6 Educational theorists

It is deemed appropriate to mention the educational theories and theorists who have analysed methods of learning which can be aided by the making process. It is important to recognise the existing theories and concepts to ensure that the act of making is not credited with offering something new when it may merely be something different. The work of Dewey (2015), Vygotsky (1930), Piaget (1980) and Papert (1995) will be discussed in this subsection.

Dewey 1859-1952

John Dewey is considered one of the most important and influential theorists in history (Glassman, 2001) and much of his influence impacts education. He believed that learners should have the opportunity to interact and be active in their learning so that their knowledge and skills development are deeper (Dewey, 2015). He also argued that it is important for learners to be able to make links between previously learned knowledge and new knowledge so that they can form a network of understanding (Dewey & Ratner, 1939: 585). His idea that education should be about becoming aware of ones' own potential and capacity more than learning a set of skills and knowledge defined by a teacher. However, many of his contemporary followers relied too heavily on the role of the learner and he warned that it was important to have a balance between teacher, learner and content to ensure that the importance of the content and role of the teacher were not underestimated (Dewey, 2015).

Vygotsky 1896-1934

Lev Vygotsky is considered one of the foundational theorists of constructivism[3]. His sociocultural theory suggests that human development is the product of a complex interaction between individuals and their society (Vygotsky, 1930: 23). He believes that this is made up of a 'zone of proximal development' which stipulates where a learner is, in terms of ability to interpret, solve problems and interact with others, compared to where they could be, regarding these things, with the guidance of a 'more knowledgeable other' (Ibid, 1930: 80). This is someone who has more knowledge or skills than the learner and could be a parent, teacher or more capable peer. He emphasised the importance of culture in a learners' development and believed that cultural difference can have a significant impact on development. Additionally, he proposed that cognitive development relied on the development of language which allows a child to formulate their thoughts with language (Vygotsky & Rieber, 1997).

[3] Constructivism is defined as the way that people learn based on their interpretation of their social and cultural environment (Vygotsky, 1930).

Piaget 1896-1980

Jean Piaget is considered one of the most influential theorists and his work alongside Vygotsky is foundational to the theory of constructivism (Cunningham, 2006: 15). His overarching belief was that acquiring knowledge and intelligence require active interaction with the learning process. He inspired the contemporary child-centred approach to learning and teaching (O'Neil & McMahon, 2005:1). He believed that a child should learn through innovation, experimentation and originality and rejected conformist notions of education. He described learning as a list of information which would absorb new knowledge to adjust what is known of existing information (Wagner, 1982: 179). One of Piaget's most influential theories was his idea of the '4 stages of cognitive development' which identify individual time periods where a type of learning and development takes place. These stages are 'Sensorimotor stage: birth-2, Preoperational stage: 2-7, Concrete Operational stage: 7-11 and Formal Operational stage: 12+'. The first stage is where a baby learns about its environment through sensory experience, the second stage is where the child learns about pictures, words and representations as well as developing an awareness of the experience of others, the third stage is where a child begins to think logically and develops reasoning skills and the fourth stage is when a person can consider abstract concepts and consider things from a social, philosophical and ethical perspective. (Piaget et al., 1980; Boden, 1988 *3rd ed.)*

Papert 1928-2016

Papert was Piaget's protégé and his work largely used Piaget's as a foundation (Papert, 1995: 105). His main focus was on the impact that new technologies had on learning. He founded the group which went on to become the MIT media lab[4] (Slotnick, 2017). Papert's theory of constructionism is based upon the constructivist theory of Piaget. Constructionism advocates student centred learning and discovery and encourages learners to use their existing knowledge to acquire more. He suggests that learners should be invited to participate in Problem Based Learning (PBL), facilitated by a teacher where learners can solve problems which triggers the

[4] The MIT media lab is a research laboratory which is devoted to addressing societal concerns by creating and adapting technologies to reconnect computers to humans and society (MIT, 2019).

learning of specific content (Harel & Papert, 1991). Constructivism is based on the idea that learning is a reconstruction of knowledge rather than a transmission and Papert's constructionism builds on to this by connecting it with the engagement of learners in the construction of real-world tangible artefacts which allows learners to physically construct their knowledge through objects (Ibid).

This section provided a short introduction to four of the most influential educationalists of the 19th and 20th centuries. Dewey (2015) was an advocate of 'learning through doing' while Vygotsky (1930) suggested that the social aspect of learning was essential for learning more. Piaget (Piaget et al., 1980) believed in a customised child-centred approach to learning experience and Papert (Harel & Papert, 1991) built upon these ideas using technology to make connections and offer real-world experience.

1.7 Power

This theme is considered relevant as it can be argued that by providing children with freedom and means of production, they are being empowered by having potential to have control of their personal social, economic and cultural outcomes. It is therefore necessary to consider what power is, how it is acquired and what impact it has on the self. The relationship between power and children is particularly significant because children may be able to have power but not have the full means or capacity to exercise it (Van Der Kaap-Deeder et al., 2016). This is discussed further in Chapter 6 in response to the findings of the data. This section will outline a brief overview of power concepts as this was the knowledge the author of this thesis had in advance of the data collection. The particularities of how power relates to children was only considered within response to this research and as such it was explored further in the literature review.

Power is the ability or capacity to do something (French and Raven, in Shafritz et al, 2015: 251-251). This thesis will consider power from a socio-political perspective and understand it as Bertrand Russell (1938) describes, 'The fundamental concept in social science is Power, in the same sense in which energy is the fundamental concept in physics' (1938:4). Michel Foucault (1979) explains this as power being relational. It exists between two entities, can be taken, traded and awarded. The value of power is perceptional and largely depends on the desire to have it. Foucault (Ibid) says, ‘Power is everywhere; not because it embraces everything, but because it comes from everywhere.’ (Ibid:93) Power relations are complex, they exist in all social interactions and can be multi-directional. Where power is exercised, resistance will push back. These relations tend to be hierarchical and so directions of power can be conceptualised on this framework (French and Raven, in Shafritz et al., 2015: 253).

A contemporary study has suggested that there are three ways to consider power, these are: ‘power with’, ‘power to’ and ‘power within’ (Haugaard, 2012). These modalities are affirmative of people’s own capacity to think and do something well. ‘Power with’ is the idea that there is strength in collectiveness. To find a common ground among a diverse group of people builds support and solidarity (2012: 353). ‘Power to’ is the idea that everyone has the power to direct their own life and what they want to do with it (2012: 353). ‘Power within’ relates to a person’s self-worth and learning to imagine and have hope (2012: 353). This central feeling of value affirms the human condition of desire for dignity and fulfilment (Jones, 2015). The last two forms of power can be described as agency, which is the ability to do something and make decisions for oneself (Emirbayer & Mische, 1998).

Power, empowerment and autonomy will be discussed in more relevant detail in Chapter 6. For the purposes of this study it should be considered that by empowering or providing the opportunity for acquiring power, there will be a shift in power dynamics which can impact future behaviours and cause unexpected changes in perception.

1.8 Intended contributions

This thesis aimed to provide theories generated from the data collected which contribute to the field of maker education. The quantitative findings support existing research and provide a foundation on which future research can be conducted regarding the types of behaviour present in informal maker education environments. Additionally, this thesis forms the largest study of its type which allows the findings to be extrapolated and generalised to other scenarios in a way that is more significant than has been possible before. Finally, the categorisation of behaviours exhibited in informal maker education environments provides an alternative framework on which to conceptualise the impact and potential of making in education.

1.9 Conclusion

This chapter briefly discussed the basis of this study before providing an indication of how this thesis will be structured. A contextual basis for the study was then given which included an acknowledgement of prior knowledge which is expected to be relevant to this research. This prior knowledge included, 'The Maker Movement', education theorists and theories and a short summary about power and empowerment. These will be considered in more detail in the formal review of literature in Chapter 6.

Chapter 2

2.1 Overview

This thesis uses a Grounded Theory methodology to generate new ideas, concepts and theories about how children use and respond to 3D printing technologies in an informal maker education setting. The new ideas, concepts and theories were based on data collected and observations noted in workshops through field notes, diary entries and for later stage research, a tally checklist. This chapter will detail the interpretation of Grounded Theory used for this study and discuss why it is appropriate for conducting this research.

2.2 Grounded Theory

Grounded Theory was used as the methodology of this thesis and as such this research will produce grounded theories. As a methodology it can be used to develop theory from the data by ensuring theoretical saturation of the data. This means that the data is read and interpreted several times to ensure that all that can be understood is taken from the data collected. As a theory it is a theoretical perspective derived from the data itself, which means that the generated theory is from the perspective of the data and not external research or theories.

Grounded Theory is used to study the experience of people with a process or phenomena by looking at patterns of behaviour. Developed largely in response to the 'extreme empiricism' (Goulding, 1998: 51) of the 1960s, Glaser and Strauss (1967: 14) believed that there was too much focus on deductive validation instead of creating new concepts and theories, that is, they felt that: 'conducting research based on the findings of other research put the development of new or alternative knowledge at risk'. Howard Payne (2016) said,

> 'the logico-deductive process is somewhat circular as a hypothesis is derived and informed by prevailing theory, which in turn informs methodological and analysis approaches and, thus, will most likely generate findings that simply reflect back to the legitimacy of the informing theory.' (2016: 52)

The theory generated from this thesis may closely resemble existing theories but it's legitimacy will be evident in the original data provided within the appendices.

Grounded Theory is primarily used in sociology and typically uses qualitative data to generate new theory(ies). Usually a large sample size is necessary to ensure that the generated theory is transferrable by inductive logic which means that the theories generated can relate to scenarios which are not the same as the one which was researched. However, there has been an evolution of the methodology and it is often used in cases of smaller sample sizes, particularly when the experience or phenomena is considered niche (Hannon, 2017). This is because it is unlikely for small sample, niche areas to require extrapolation beyond the parameters of the original study.

There are three main types of Grounded Theory. It was established by Glaser and Strauss in 1967 but has evolved into three well defined branches and Grounded Theory research can usually be identified as either Glaserian (classic), Straussian (developed alongside Corbin) or Charmazian (constructivist) Grounded Theory- a definition and broader explanation of each of these types will be explained in section 2.4.

However, all Grounded Theory generally follows this process:

Phase 1: Data collection
Phase 2: Note taking
Phase 3: Coding
Phase 4: Memoing
Phase 5&6: Sorting and writing

Depending on the type of Grounded Theory, different methods of data collection can be used. Typically, data is collected using qualitative methods as value is bestowed on qualitative data by leading Grounded Theory practitioners (Balawa, 2014). However, quantitative data can be collected where appropriate. In Glaserian Grounded Theory everything can be considered as data, including adverts, branding, sketches etc. 'All is data' (Glaser, 1978: 8). Glaser and Strauss (1967) state that the most important thing about Grounded Theory data collection is that it is vast. There must be significant quantities of data to ensure it is possible to do comparative analysis repeatedly until there are no further possibilities within the data. Once the initial stage of data collection is complete, the data must be analysed and notes taken to begin to form lists of categories so that patterns can be found. Once the notes have been made, they can then begin to be coded- that is, patterns can be identified to create categories against which the data can be compared and all future data can be tested against these categories. Any deviations can be considered as potential new categories, and all collected data can be compared to these new categories (Glaser and Strauss, 1967). This comparative analysis will be done repeatedly until theoretical saturation has been achieved. Theoretical saturation is defined by Strauss and Corbin (1998:143) as 'The point in category development at which no new properties, dimensions, or relationships emerge during analysis.' Once this has been done, there will be a framework for the new theory based on the categories and sub-categories identified in the analysis.

2.3 The suitability of grounded theory for this thesis

Grounded theory is an appropriate methodology for this thesis as the use of newly accessible technologies in informal maker learning environments, is a relatively new phenomenon. Additionally, research surrounding 'The Maker Movement' does not have a defined research paradigm as the points of interest and inquiry are multi-disciplinary. As such the fields of research focused on this area include design research, Human-Computer Interaction (HCI) and engineering. Therefore, there are many possible approaches to this research with most being based on deductive reasoning (Patokorpi & Ahvenainen, 2009: 113). This thesis had the opportunity to include several thousand participants and therefore presented the opportunity to produce abductive reasoning-based theories, which require a large data-set. Considering this, there was an opportunity to generate new theory based entirely on the observation of phenomenon and not influenced by pre-determined interpretations or ideas. Additionally, this research sought to understand human behaviour and motivations which are complex and therefore a quantitative approach would be limited with regards to what it could offer in terms of information or knowledge.

There is a consensus that the Grounded Theory founders did not intend for their method of conducting Grounded Theory to be prescriptive and that researchers should adopt and adapt their approach for their own research. (Bulawa, 2014: 145;

Glaser & Strauss, 1967*)* A full description of the interpretation of Grounded Theory used for this study can be found in section 2.6.

As discussed in Chapter 1, Grounded Theory practitioners suggest that the researcher should have theoretical sensitivity (Charmaz, 2013) and therefore a literature review should come from the data and not in advance of it. The review of literature can be found in Chapter 6 which was carried out after the analysis of data. There is a brief overview of relevant themes which the researcher was already familiar with. This can be found in Chapter 1.

2.4 Types of Grounded Theory

Glaserian

Glaserian Grounded Theory is considered as classic Grounded Theory (Glaser & Holton, 2004). It is the version that most closely resembles the original archetype, laid out in the book, 'The Discovery of Grounded Theory: Strategies for Qualitative Research' (Glaser & Strauss, 1967). The original method was developed by Glaser and Strauss together. However, Strauss moved towards pragmatic relativism[5] and wanted the method to be more open to multiple perspectives. Strauss felt that the original method relied too much on a discovery rhetoric which suggested that an interpretation was correct rather than open to multiple interpretations over time (Balawa, 2014).

Glaserian Grounded Theory is situated within a post-positivist paradigm and views data through the lens of critical realism. Considering this position, the researcher must be an objective, detached observer (Goulding, 1998). To achieve this detachment, Glaser (1978) believed that the researcher should know as little as possible and start the research with no hypothesis. Therefore, there should be a latent literature review. This ensures that only the data itself is generating the theory.

[5] Pragmatic relativism in this context refers to Strauss' belief that Grounded Theory had been too idealistic and in reality a more realistic approach was needed to ensure the longevity of grounded theories.

Glaser (1978) refers to this need for theoretical sensitivity in Grounded Theory. He said that this is essential for open coding, the type of coding that he favoured, as it allows the researcher to see the categories that can contextualise the data theoretically. Glaser and Holton (2004:43) say that,

> 'the ability to generate concepts from data and to relate them according to normal models of theory in general, and theory development in sociology in particular, is the essence of theoretical sensitivity. Generating a theory from data means that most hypotheses and concepts not only come from the data but are systematically worked out in relation to the data during the course of the research.'

The Glaser approach tends to emphasise a slogan that is often associated with Grounded Theory, that is, 'all is data' (Glaser, 1978: 8). He says that everything can be used as data, not just the transcript of a conversation: anything that will help to understand the experience or phenomena can be used. With regards to verification, Glaser (1999), suggests that grounded theory can only be verified by performing subsequent quantitative analysis. This is an interesting point of Glaserian Grounded Theory as it appears to reflect back to the 1960s research rhetoric which valued only quantitative data. However, despite the contemporary acceptance and believed value of qualitative data, there is still some skepticism surrounding Grounded Theory as a methodology (Mjøset, 2005: 387). As such, confirmation research using quantitative data may help to demonstrate the significance and robustness of the research.

Straussian (and Corbin)

The Straussian and Corbin version of Grounded Theory differs from classic Grounded Theory in terms of its philosophical perspective. Charmaz (2013) said that Strauss regretted the 'discovery' rhetoric of the 1967 book, 'The Discovery of Grounded Theory: Strategies for Qualitative Research' (Glaser & Strauss, 1967), which positioned Grounded Theory as a methodology and from which all Grounded Theory research stems. He later felt that 'discover' is too absolute and not a true reflection of what the generation of theory is (Balawa, 2014). Straussian Grounded Theory can be viewed as being more open to the plurality of perspectives and interpretations. This pragmatic relativist approach allows for a multi-perspective interpretation of the data and more opportunity for category intersection and interaction. Strauss advocates that the researcher should be actively engaged with the research as an attempt to better describe and understand the world as the participants perceive it to be (Howard-Payne, 2016).

In terms of the data coding and analysis, Straussian Grounded Theory uses axial coding which is defined as, ‘the data analysis process whereby data are assembled to highlight the linkages between the various categories of the grounded theory’ (Strauss & Corbin, cited in Howard-Payne, 2016). This highlights one of the technical criticisms that Glaser had of Staussian Grounded Theory. He said that by using this type of data analysis, the connections between the data are not authentic and it stops concepts from emerging freely (Burnard, 1991). The inauthenticity to which he refers describes interpreted connections between data points which were not directly identifiable within the data. However, Strauss and Corbin use this as a means to ensure that theoretical saturation has been achieved.

Strauss and Corbin (1990) do not support the idea of verification through quantitative data, instead they believe that verification can only occur using vast amounts of data and thorough comparative analysis.

Charmazian (Constructivist)

Charmazian Grounded Theory is considered an amalgamation of Glaserian and Straussian Grounded Theory but on closer exploration of her philosophical perspective, though unique, is more in line with Straussian. Since Strauss’ death, Corbin his co-author has moved their theory closer to Charmazian Grounded Theory (Charmaz, 2014). Charmaz (2013) takes a constructivist approach, which is an evolution of Strauss’ pragmatic relativism. Strauss believed that pragmatic relativism was necessary to ensure that as many perspectives were considered with regards to the data as possible. However, Charmaz (Ibid) thinks that it is important for the researcher to think about the people he or she is working with in advance of starting the research. She also thinks that the researcher should consider his or her own world view, status, prestige and prejudices. She believes that Grounded Theory involves a co-construction of data whereby the researcher and participant both influence the data, therefore she believes it is important to address that in order to understand how the research and resulting theory may be skewed in relation to experience.

Charmaz (2013) argues that theoretical agnosticism is preferable when conducting Grounded Theory. It is important for the data to lead the exploration of theory and not to come from it. However, she does acknowledge that some type of literature review may be required in advance for example, for proposals in funding applications but where possible to avoid this. She advocates a literature review that responds to the data. However, she acknowledges that broad concepts of enquiry used to build a framework such as 'identity', 'self' or 'time' may be appropriate but suggests that if they do not fit, to let the data direct the research (Ibid). Charmazian Grounded Theory advocates the use of line-by-line coding which can be done quickly and produces many themes and concepts. She then adopts the focused, axial coding that Strauss advocates in order to select which codes should be expanded into categories which will eventually result in the development of theory.

With regards to verification, Charmaz avoids using the empirical data language and says that she does not believe that data can or should be verified but it should instead be checked (Allen, 2010: 4).

2.5 How Grounded Theory is conducted

The following section will provide an outline of how Charmaz suggests that Ground Theory should be carried out. This section will be followed by a description of how this will be adapted for the purposes of this study.

Theoretical Sampling

Charmaz believes that analysis of data during the collection phase helps the researcher to focus early. When leads in the data become apparent, which were not anticipated it allows more time to explore these leads. She says that data collected like this is far more convincing, persuasive and authentic (Morse, in Bryant & Charmaz, 2007: 229).

Coding

When starting to code the data, observed actions and processes should be noted. It is important to look at what is happening in the data and as such the researcher should look for the 'doing words' or verbs. Charmaz discusses the structures which exist in social interaction and explains that constructivist Grounded Theory focuses on change rather than these structures. She says that when structures exist, for example in dominant institutions they remain in place because people act in a routine way This perpetuates and reifies these structures. Constructivist Grounded Theory is based on social constructionism and considers how individual actions impact the processes and structures (Holton, in Bryant & Charmaz, 2007: 265).

Line-by-line coding

Charmaz is an advocate of line-by-line coding. She says that it can be done quickly with practice and is spontaneous. (Ibid: 265) She uses it as an interrogative device and not an essential procedure but says that it can be useful when the data is stagnating.

Axial coding

Axial coding is the phase which comes after line-by-line coding. Axial coding involves searching the data for ‘incidents’. Charmaz defines an incident as an action that leads to an outcome. She says that all incidents must be noted even the ones that seem routine or mundane (Ibid: 265).

Memo-ing

Charmaz recommends that memos be used as a type of research diary or methodological journal. It is not a restrictive method, a lot of the memos come from codes and developing categories, others come from the gaps and links between categories. Memos help to clarify the usefulness of categories and the practical implications of the data. Charmaz says that memos are part of a process of theorising. They provide the opportunity for researcher reflection (Singh, 2018: 5).

Recoding

Some grounded theorists prefer to go back through the data to re-code it once the initial phase of coding is complete (Soklaridis, 2009: 730). However, Charmaz argues that accuracy is not as important, and it is acceptable to check codes and categories against new data.

Deep analysis and theory development

Charmaz proposes that deep analysis is the breaking up of data to find what it is comprised of (Trainor & Graue, 2013:119). It is important to identify the conditions necessary for the emergence of these properties. It is at this point that the researcher should define what they are talking about and identify what it means empirically and what the implications are. There is a particular emphasis on checking what everything in the data means, in particular the taken for granted meanings that have worked their way into well-known theories (Ibid).

The development of theory occurs as categories are developed which lead to the definition of theories. The questions a researcher should ask are: what is being spoken about within the category and will that change as more data is collected and further analysed. The word 'theory' itself is generally defined by the factual evidence, an explanation and prediction (Ibid).

Saturation

Charmaz states that there are two types of theoretical saturation; the saturation of data and the saturation of concepts (Ibid). Finding all possible properties of a concept is different from seeing the same answers coming up repeatedly as Grounded Theory is a development of concepts. Additionally, there is saturation by definition and saturation by claim. It is important to realise that saturation is unlikely to occur after just a few cases (Engward, 2013). Constant comparison is necessary as it demonstrates that there are no further categories and therefore saturation has been reached. However, this means that there is no definitive end point to the research and as society, opinion and culture change, so too will the concepts and categories. Therefore, saturation can only exist for a finite period of time. Researchers have to decide when that is enough although they may come back to it after several years have elapsed (Rowlands et al., 2016).

2.6 Interpretation of Grounded Theory for this study

Charmaz (2013) and Bulawa (2014) explain that Grounded Theory was not intended to be a prescriptive methodology but rather that researchers should consider the recognised types and then adopt or adapt these to suit their particular research. This section will outline the interpretation deemed appropriate for conducting this study.

First, a comparison table will be provided before a detailed plan is laid out to explain how each phase of research will be conducted and analysed.

Phase	Glaserian	Strauss & Corbin	Charmaz	Milne (author)
Phase 1: Data collection	Yes- *qualitative and quantitative*	Yes- *qualitative, multi-perspective awareness*	Yes- *begin analysis at this stage*	Yes- *qualitative and quantitative*
Phase 2: Note taking	Yes	Yes	Yes	Yes
Phase 3: Coding	Yes- *open coding*	Yes- *axial coding*	Yes- *line-by-line, then axial*	Yes- *open, line-by-line and axial*
Phase 4: Memoing	Yes	Yes	Yes	Yes
Phase 5: Sorting	Yes	Yes	Yes	Yes
Phase 6: Writing	Yes	Yes	Yes	Yes
Phase 7: Checking findings against quantitative research	Yes	No	No	Yes
Interpretation style	Objectively detached	Pragmatic relativist	Constructivist	Constructivist

Table 1- Comparison between methods of different types of Grounded Theories

Table 1 (above) shows that in terms of how the Grounded Theory will be carried out, this study will follow a Glaserian approach to Grounded Theory with Charmazian influences, particularly with regards to the interpretation of the data and prior awareness of personal biases.

This study includes the quantitative information[6], observation and diary entries from stage 1 of this research, of 207 3D printing workshops which included 2496 participants. A detailed description of how Grounded Theory is used in the study is provided below.

Phase 1: Data collection- field notes were taken and stored for later analysis at 207 3D printing workshops. These field notes included, how many participants attended, what their ages and gender were, how the workshops were funded etc. alongside detailed diary entries. (Chapter 4)

Phase 2: Note taking- Once the first stage was completed notes were taken to begin a filtering of the data. The number and variety of workshops and participants included was too vast to take forward for analysis within the scope of a PhD study. As such, a decision was made with regards to which workshops to take forward to phase 3.[7] (Chapter 4)

Phase 3: Coding- Open ended and Line-by-line coding were done initially to ensure that as much information could be taken from the data as possible. After this, axial coding was conducted to identify a range of relevant events.[8] (Chapter 4)

Phase 4: Memoing- In order to make the relevant events more manageable for the scope of this study the number of relevant events were grouped into 'potential categories'. (Chapter 4)

Phase 5: Recoding- The potential categories were then checked against the entire data-set to find any other examples which may have been missed in the first round of coding. Additionally, the first round of coding was checked for any instance of a particular behaviour. However, on the second round, any workshop which exhibited

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[6] Quantitative information included number and age of participants, length of interaction, gender etc. see full list in Chapter 3.

[7] The total number of workshops taken forward to phase 3 was 148.

[8] There were 71 relevant events. 'Relevant events' was the description used by author in place of themes or categories- it was felt that this was more descriptive of the particular situation.

a particular behaviour was noted. This is an important distinction to make as if each individual's behaviour was noted the data could be skewed by a particularly active or responsive group. (Chapter 4)

Phase 6: Sorting- These potential categories were then considered in terms of occurrence. Any which occurred in 50% or more of the workshops were taken forward as categories. (Chapter 4)

Phase 7: Checking using quantitative research- In line with Glaserian Grounded Theory, this study used a confirmation study to verify the findings. Despite many theorists feeling that this is unnecessary (Allen, 2010: 6; Bailey, 1994: 55) it was considered important for this research to mitigate the limitations of this study with regards to the way in which the research was recorded. See Chapter 3 for details. A confirmation study showed that similar results were achieved under traditional research conditions. (Chapter 5)

Phase 8: Statistical analysis- Using this quantitative confirmation research, statistical analysis was carried out on the differences between types of workshop. This provided information regarding the significance of the findings. (Chapter 5)

Phase 9: Writing- Using the original findings alongside the findings of the confirmation research, soft theories were generated and proposed. (Chapter 5)

Phase 10: Literature review- a review of relevant existing literature was conducted after the generation of 'soft' theories in order to contextualise this study. (Chapter 6)

Phase 11: Theory generation- By contextualising the soft theories within literature this thesis proposes new theories regarding children's use of 3D printing technologies within informal maker learning environments. (Chapter 7)

2.7 Conclusion

This chapter has explained what Grounded Theory is and why it is an appropriate methodology for this study. An overview of the well-known Grounded Theory practitioners was provided to demonstrate the variety of approaches in the literature. This study used a Glaserian approach, with Charmazian influences. Finally, a detailed plan for how Grounded Theory was carried out within this study was provided with reference to chapters which included each phase.

Chapter 3

3.1 Overview

This chapter will detail the methods used in this study. It will explain why these methods are appropriate and how they were carried out. The study was split into two distinct research stages. The first stage was concerned with the collection of a broad range of qualitative and some quantitative data, whilst the second stage was designed to quantitatively check the findings of the first stage. The first stage of data was collected through workshops, observations, field notes and diary entries. The second stage used a tally-checklist and statistical analysis. In the following sections each method will be described and justified before a description of how the methods were carried out will be given.

3.2 Workshops

As a research method, a workshop is not commonly recognised as a means of collecting data (Hannington & Martin, 2012) and thus requires a clearer definition regarding how this was used in this research. The word 'workshop' was once defined as a place where things were made or repaired (Ørngreen & Levinen, 2017:71). Since the late 1940s however, there has been an evolution in the general use and accepted meaning (Ibid). Ørngreen and Levinsen (Ibid) describe this evolution. They discuss the change from creative problem solving (CPS) groups of the 1940s to the dissemination of information about societal challenges, policy making, technological changes, organizational changes in innovation and design. This later led to a large number of workshop formats being developed by practitioners such as Isaksen et al., 1994; Vehar et al., 1999 and Puccio et al., 2007. These workshop formats include themes such as community building (Peck, 1990), future forecasting (Mullert and Jungk, 1987) and participatory design (Ehn and Kyng, 1987). Since the late 1990s, the word 'participation' has become almost integral to the idea of what a workshop is from a research perspective (Hannington & Martin, 2012).

From the above overview of types of workshops that have appeared in literature since the late 1940s, there appear to be two main types of workshops that exist as processes. The first is a workshop with an objective, where participants gather and attempt to solve a problem. A recent example of this in design is the 'Make the Breast Pump not Suck' hackathon which took place at the MIT media lab over the last weekend of April 2018 (MIT, 2018). Designers, engineers and makers with different ideas, passions and skillsets got together for 48 hours to work together to make a better solution to the existing breast pump. The other dominant type of workshop that appeared through the literature was workshops that taught participants a particular skill, for example, a bookbinding workshop, where participants attend knowing relatively little about something but leave having learned a new skill. In this case participants left having managed to successfully bind a book (Kealy-Morris, 2015: 126).

Workshops are typically used to describe a physical place to do work, or as an event that takes place over a limited period of time to learn a skill. However, in the literature there are many instances where researchers have used workshops as a means for gathering information from participants. The participants usually have not taken part in order to be a research subject but instead to solve a problem or to learn a new skill and the fact that they have become part of the research is incidental. This adds an interesting dimension to the research as the motivation of the participants is perhaps different than that of other research participants. Darsø (2001) says that, 'using workshops as research methodology is an especially useful approach in studies that are emerging and unpredictable' (2001:11).

3.2.1 Role of researcher-facilitator

As Darsø (2011) noted the use of workshops as a research method provide useful opportunities. This includes the opportunity for the researcher to be a researcher-facilitator which offers some benefits regarding balancing power dynamics (Adler and Adler, 1987). Gold's (1958) typology of observation can be used to situate this research and understand the variable roles in observation. The researcher-facilitator was a participant of the group and an observer but the role of facilitator allowed greater freedom to observe without losing the detail that a researcher may typically lose due to participant reluctance to interact due to the negative power dynamic.

A facilitator will generally actively take part in the group and, to a person external to the group, they could appear to be a member of the group. However, a facilitator brings the tools and materials into the space and fixes or helps with problems experienced by other group members. This setup allows the facilitator to fit almost seamlessly into the group so that the other participants stop treating them as ‘other’ or ‘different’. Adler and Adler (1998) discuss the ‘peripheral membership role’ where the other participants give the observer limited access or membership to their group. This was the case in almost all workshop facilitated for the purpose of this research.

Impact of this role on credibility of data collected

Creswell (2009) discusses the flaws of workshops as a research methodology as the quality of the data is dependent on the facilitator and method of data recording. In this case, as is often the case with workshop based research (ibid), the researcher was the facilitator which meant that some data was inevitably recorded retrospectively and therefore the data cannot be entirely described as primary. To deal with this problem Denzin and Lincoln (2013) suggest that the data should be recorded using ‘thick notes’ which focus on choices that were made. Thick notes are made up of thick descriptions, which Denzin and Lincoln (ibid) define as a description which is replete enough with detailed information to make the reader feel that they have, or could have, witnessed the phenomenon described.

In the case of this study the benefits of using workshops as a method were considered significant enough to counter the negatives. Access to tools of digital fabrication is still limited (Dougherty, 2016). As such, many participants may not otherwise have the opportunity to use these tools freely in a setting outside of an organised structured workshop. Additionally, by playing the role of researcher facilitator the number of workshops conducted was not limited by external factors, which allowed this study to draw on observations from hundreds of workshops.

The drawbacks to playing this role were that some data was recorded retrospectively and that being personally involved with the participants in the workshop setting could limit emotional objectivity. In order to reduce the negative impact of these drawbacks the data was recorded as soon as and as thoroughly as possible after the workshop when it was not possible to record all diary entries at time of observation. With regards to emotional objectivity the researcher made an effort to be as objective as possible but did not ignore or omit observations which demonstrated emotional response or engagement as it felt dishonest to do so. To limit any potential negative impact of this, the researcher was committed to complete transparency so that all data can be trusted to be a true representation of the experience and observation including the researcher's role in it and as such the data can be treated consistently.

3.3 Field notes

Field notes can serve as an aid in constructing thick descriptions of a study, context, group, activity etc. (Phillippi and Lauderdale, 2018). Before qualitative research was accepted as good research, field notes were generally a researcher's personal notes and ideas. Over time they began to be accepted as an additional layer of data which could be analysed (Ibid, 2018). They can now form the key part of a study and will often be used several times at different stages of analysis to identify anything new they may offer at a later stage.

Recording field notes is a suitable method for this research as it is a simple and effective way to document the observations of workshops. These notes were then used to create thick descriptions as Denzin and Lincoln (2013) suggest, as a solution to the limitation of any delay in documentation. For example, as the researcher was facilitating the workshops it was not always possible for observations to be recorded immediately.

3.4 Diary entries

Diaries are a widely recognised tool of social scientists who use them as a means of recording ethnographic data. Pedgley (2007) explains that the use of diaries for research is rare because they are associated with studies taking place over a long period of time. Further, the observations will be analysed as they are written and not considered through any theoretical lens (2007:470). Pedgley (Ibid) proposes that diaries can be used for self-reflective documentation of design practice. However, considering the benefits he cites, including the ability to record facts as well as subjective information, it was believed that a diary was a valuable method for recording the workshops in this study. This method offered the opportunity to share otherwise 'silent cognitive processes' (2007:471) which are important for understanding the overall experience and providing details necessary to construct deep understanding in readers. Additionally, stage 1 of this study took place almost every day over an 18-month period. The observations were to be analysed as they were recorded and as such the usual limitations of diary keeping in research do not apply here.

3.5 Second stage research

After all the workshops had been conducted, recorded, analysed and 'soft' findings determined, a second round of research, was conducted to verify these findings. As discussed in Chapter 2, it is generally accepted that verification research is not necessary in Grounded Theory as the general acceptance and value of qualitative research has been recognised. However, due to the potential of delayed documentation of data as well as the lack of hypothesis which could lead to incomplete descriptions of observations, it was considered advisable for verification research to be conducted to mitigate the limitations of the first stage of research.

The first stage of research produced findings based on the observation of particular events or behaviours observed within the workshops. To test the occurrence of these events and behaviours, a tally-checklist form was created (See appendix 6). This allowed the researcher-facilitator to easily record whether or not a particular event or behaviour had occurred and by how many participants. These forms could be filled in with accuracy at the time of behavior or event occurring as well as for a short time afterwards due to the defined nature of the information sought.

3.6 Tally-checklist

A tally-checklist is an adapted version of the recognised checklist method with space for a 'running account' which allowed the number of times a defined event or behaviour had occurred to be recorded. By using this method, one which has been considered a valid approach to documenting observation since the 1920s and 1930s (Jersild & Meigs, 1939: 474), for the second stage of research, it was hoped that it would provide an additional layer of rigour to the findings of the first stage of research, which was carried out using a less orthodox approach which can be considered vulnerable to criticism.

The tally-checklist for the verification research of this study can be found in appendix 6. At the top of this form there was space to write the date, type of workshop and the number of participants. Below this there was a table with the first column detailing the defined event or behaviour, the second column asked whether this event or behaviour occurred and the third column provided a space to keep a running tally of how many times the event or behaviour occurred.

The verification research was conducted by facilitating a further 40 workshops which was deemed an appropriate number of workshops after the initial 'soft' findings were arrived at.[9] See Chapter 5 for details on this process.

3.7 Ethical considerations

This study was based upon the ongoing non-academic work of the author. She provides 3D printing workshops in schools, youth organisations, children's hospitals as well as hiring spaces from which to run her own workshops. Therefore, this study does not introduce any additional risk as children were attending whether or not the workshops were being observed.

In line with Edinburgh Napier University's ethical approval process, the research proposal alongside a draft consent form (See appendix 1) was provided to the ethics committee for approval. After approval was granted, the workshops to be observed for this study were considered. Instead of choosing a particular quantity of workshops, the quantity of which may be considered arbitrary, a timeframe was set and all workshops within this timeframe, where observation was appropriate and consent was given, were included in this study. The timeframe was set at 18 months.

[9] 'Appropriate' in this context was defined as the number of additional workshops deemed necessary to correlate the original findings.

Where possible the forms were provided at least one week in advance of the workshop. However, at times when the author was not in contact with parents directly, it was not always possible to provide the forms until immediately before the workshop and in rare cases immediately after. In cases where consent was not granted prior to the workshop, behaviours of these children were noted retrospectively. In cases where the majority of participants had not given prior consent, the observations were not used in the study.

3.8 Application of methods

This section will provide a detailed plan of how the research was conducted using the methods defined above. It will explain the organisation, planning, delivery and documentation process utilised in this study.

3.8.1 Organisation of workshops

The workshops observed in this study were based on workshops already provided by the researcher as part of her business which provides 3D printing education across Scotland. The workshops took place in a range of scenarios and included youth clubs, birthday parties, holiday programmes, faires, private tuition sessions and regular clubs. The researcher provides these sessions on a daily basis as part of her job and as such no sessions were arranged for the sole purposes of observation. The workshops that took place after ethical approval was given, where observation was deemed appropriate and where consent forms were completed, within the predefined 18-month timeframe between 2016 and 2017 were included.

3.8.2 Planning of workshops

As the workshops are already organised as part of the researcher's regular work the planning necessary was minimal. The researcher explained to parents or youth workers who booked the workshops via email or phone call that she would like to observe and document the workshops for the purpose of her PhD.[10] She made it clear that they had the freedom to refuse consent without fear that the workshop would be cancelled to ensure that consent was informed and unpressured. When they agreed,

[10] All parents and youth workers agreed that this was acceptable subject to completed consent forms by parents.

she gave consent forms to parents and youth workers for distribution. At the beginning of each workshop the researcher collected consent forms and in cases where parents had not been provided with one, she gave them the opportunity to complete one.

3.8.3 Delivering the workshops

All workshops delivered had the same basic structure. However, regular sessions had an additional option of using CAD software to design a model to be produced on the 3D printer. The researcher-facilitator arrived before the children and set up an Ultimaker 3D printer and up to 14 3D printing pens depending on the number of participants. She also placed a selection of reels of filaments which the participants could choose from. Workshops typically lasted between 1 and 2 hours depending on the setting, i.e. if a youth club lasted 90 minutes, then the workshop would also last 90 minutes.

When all participants had arrived and were ready to start the researcher-facilitator introduced herself and explained that she was interested in learning from the children as much as they would be learning from her and that she may take notes during the workshop. She told them that if anyone was uncomfortable with being written about, she would not do so even if she has parental consent. The researcher-facilitator felt that this was necessary to minimise negative power dynamics where a child may feel that they had little or no control of their present situation.

The researcher-facilitator then turned the 3D printer on and loaded a pre-prepared file. She then explained how the 3D printer works making a comparison with inkjet printers in order to link prior knowledge of how they know a ‘normal’ printer works with understanding how a 3D printer works. She then discussed what a 3D printer can be used for and encouraged conversation and questions between participants. After the conversation had concluded she moved onto the 3D printing pens, leaving the 3D printer to continue printing.

The researcher-facilitator explained that the 3D printing pen nozzle can get very hot and made an analogy between an oven in order to link knowledge and understanding of something which heats to the same temperature that they were familiar with.

Thus, utilising the theory of knowledge building as proposed by Piaget (in Boden, 1988, *3rd ed.*). She provided gloves for the participants to wear to protect their hands. She then showed them how to plug the 3D printing pen into extension cords on the tables before turning them on. ABS and PLA filament were provided, and she explained the differences between these, both with regards to physical differences as well as the difference in how the materials perform when drawing with the 3D printing pen. She then demonstrated how to use the 3D printing pens when drawing on paper and in the air (see figures 30-34). A number of child-themed templates were provided including popular television and film characters, animals, transport, letters, shapes etc.

There was a maximum of 14 3D printing pens available at all workshops. This meant that in most workshops, children got a pen to use by themselves. However, in some cases it was necessary to share one between two participants.

Once the researcher-facilitator had finished demonstrating the 3D printing pen the participants were then free to use the 3D printing pens to make whatever they wanted. Participants could make as many items as they liked during the workshop and had access to a minimum of 10 different colours which they could change as often as they liked.

3.8.3.1 Additional option for regular workshops

At the 3D printing workshops that had the same regular attendees, the children and young people had the option of using laptops with Google SketchUp CAD software. These could be used to design their own models which could be printed on the 3D printer either at the next workshop or in advance of the next workshop. The laptops were laid out next to the 3D printing pens and filament alongside some information sheets which had some short step-by-step project ideas to show them how to use the basic tools. In cases where participants showed an interest in using the laptops the researcher-facilitator provided a short demonstration of how to use the software and its basic tools. For all workshops with the same regular attendees within this study, there were two laptops available for use.

3.8.4 Documentation of workshop- stage 1 research

The observation of the workshops conducted in stage 1 of the research were documented using field notes and diary entries. Field notes were taken throughout the workshop where possible and a diary entry was completed as soon as possible after the workshop using the 'diary entry form' designed by the author. This form, an example of which can be found in appendix 4, provided space to record a general description of the workshop. There was also space to record the number of male participants, number of female participants, the objective of workshop, how participants accessed workshop, options available alongside the workshop, length of interaction, length of workshop and age range. These additional documentation categories will be expanded upon below.

Number of male and female participants

It was important to record the number of participants to understand the size of the sample. The number of participants were further categorised into the numbers of males and numbers of females in order to record any differences in attendance or exhibited behaviours between genders[11].

Objective of workshop

This was recorded to ensure that the objective did not skew other information. For example, if it was a 'Women in STEM' event then the fact that more females attended than males would be unsurprising as the event was targeted at females. Additionally, it helped to illustrate expectations and motivations for attendance.

Access to workshop- paid per person or organisation

This category was used to highlight the differences in access. 'Paid per person' indicates instances where each participant was paid for individually i.e. by their parent. Organisation in this instance means that the child participated free of charge and instead an organisation paid for the whole workshop in advance. This section may show differences in motivation for attending.

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[11] Gender was identified by the pronoun used by parents or youth worker staff. Where this was not made explicit an assumption was made based on which gender the child most closely resembled. However, the author acknowledges that in cases where an assumption was made the recorded gender cannot be considered as certain.

Options alongside the workshop

Some workshops were delivered as part of a wider programme of activities and therefore participants could choose to participate in a 3D printing workshop or a number of other activities including boxing, cooking, computer games, etc. This category was provided to illustrate motivation or desire to take part in the context of choice. Having a choice limits the possibility of the participants choosing 3D printing solely due to lack of alternative choice.

Length of interaction

When a workshop was paid for in advance there was often a financial incentive from the organisers to have as many participants take part in the activity as possible. Therefore, despite the recommended length of workshop being 60 minutes for up to 14 participants it was not unusual for organisers to split the time and have two groups of 14 participate within the length of a normal workshop.

Length of workshop

There is space for this to be recorded to contextualise the 'length of interaction' category. This is valuable to demonstrate time it took for certain ideas, attitudes and objects to be created, learned or developed.

Age range

This section simply recorded the age of participants. This can be used to cross-examine the differences between participation for boys or girls at different ages.

3.8.5 Documentation of workshops- stage 2 research

The observation of workshops conducted in stage 2 of the research were documented using a tally-checklist which allowed for pre-defined behaviours to be checked for. The tally-checklist form (see appendix 6) could be completed with accuracy during and immediately after the workshop. This form provided quantitative data regarding the number of workshops in which a predefined event or behaviour occurred as well as the number of participants who exhibited this pre-defined behaviour. This data could then be statistically analysed to determine the significance of differences across types of workshop.

3.9 Subjective data and its validity

The conventional approach to research dictates that subjectivity should be avoided and constrained when conducting scientific enquiry (Kuhn, 1977). However, qualitative research increasingly challenges this notion (Given, 2008). There is a growing consensus that objective thinking is contextualised within subjective thought and therefore subjectivity is necessary to coherently analyse a situation or set of data (Ibid).

Peshkin (1988) was an advocate for the role of subjectivity in research and argued that it gave the researcher a useful means for shaping data and it was the researcher's challenge and responsibility to be aware of this though self-reflection. However, Barone (2000) says that measuring research as subjective or objective is irrelevant, and it is whether the research is rigorously evaluated to provide useful insights that is important.

Subjective data offers a useful way to gather information that may otherwise be missed or influenced by an objective approach to the research (Fontaine & Haywood, 2017; Erhan et al., 2019). However, Fontaine and Haywood (2017) highlight that subjective data can lead to biased responses and therefore can skew the research. This illustrates the necessity for self-reflection as noted by Peshkin (1988) on the part of the researcher and a commitment to limit the negative impact of subjectivity and introduce objectivity where appropriate.

Evaluation of type of data presented in this study

The data presented in this study was gathered using observation. This means that the researcher-facilitator noted observations of behaviours in diary entries. As the researcher was interpreting these observations this data is considered subjective. It is plausible that someone else may have interpreted what was happening differently from the researcher. In order to balance this and limit the inconsistencies associated with subjective data during the sorting stage of analysis any observed behaviour which was deemed debatable or could be misidentified was discarded. This meant that only behaviours that were considered universally understandable by commonly accepted definitions were taken forward for further analysis and testing. These behaviours were described in chapter 5 to ensure that should the research be repeated then the researcher would know how the observed behaviours were identified.

The table below provides a rationale for the way these behaviours were observed, identified and understood.

Behaviour	How behaviour could be identified	Limitation of possible subjective inconsistencies
Problem solving	Child found it difficult to do or achieve something but managed to work it out.	This observation requires that the observer be aware of what the child was attempting to do and as such to ensure that any future researcher be able to conduct this research consistently they should immerse themselves in several workshops in advance of beginning research so that they are able to identify how children use the tools and what they might try to do with them. Other than this, it is reasonably assumed that someone would be able to identify that this behaviour had taken place simply by watching.

Social learning	Child learns from peers by copying their method of making or by responding to something they said by asking questions or adding information to it indicating that they were making meaning together.	This observation is considered a general interpretation. By hearing and seeing children copy methods and have conversations about particular topics such as Roman Britain then learning is assumed to be taking place. (See diary entry 54)
Proud of achievement	Child verbally said they were happy with what they made or approached the researcher-facilitator or a parent to show them what they had made.	This subjectivity of this observation is limited to the definition of pride. Otherwise it is assumed that anyone would be able to identify this behaviour using the behaviour description.
Communicated with peers	Children spoke to other children in the room.	This observation could be described as objective as the way in which this observation was measured was through binary means- they did or they did not. In this case if a child spoke to another child then this behaviour was considered to have taken place.
Experience of agency	The observation of a child doing or achieving something which resulted in them feeling capable demonstrated by them verbally confirming	The identification of this behaviour may rely on the researcher being familiar with the workshop. If the researcher were to attend several workshops to

	that they could now do 'something'.	acclimatise themselves to the situation then it is deemed likely that they would be able to identify this behaviour.
Satisfaction with outcome	Child smiling at end of class and holding onto their creations or verbally telling a parent/carer that they had a good time in the class.	The observation of this behaviour is straightforward and relies on the researcher simply listening to the children talking to parents and interpreting the expressions on the children's faces with a smile indicating enjoyment in this context.

Table 2 A description of how the identified behaviours were defined

Data in this study

The categorisation of data in this thesis contextualised in the above table suggests that several behaviours may be considered objective when identified through a set of clear instructions. 'Social learning', 'expression of pride in achievement' and 'communicated with peers' are all accompanied by clear instructions which it is considered that that the majority of people in the position to conduct research could follow to identify. 'Problem solving' and 'experience of agency' behaviours would require the researcher to be familiar with the workshops so that they may identify these behaviours as they are expressed in two parts: 1. Child struggles to do something and 2. Child manages to do something and then says or shows they are happy with their creation or indicates that they are now aware that they are capable of doing something. The final behaviour, 'satisfaction with outcome' could describe several of the other behaviours and at times relied on researcher interpretation of facial expression. However, given the context of the observation the margin for error in interpretation is reduced somewhat but this remains the most subjective observation of behaviour carried forward for phase 2.

It is therefore proposed that because phase 2 of the data collection made use of the clear descriptions to help the researcher consistently identify the defined behaviours that the subjectivity of this data was reduced as far as possible and in some cases the data could be described as objective. Therefore it could be considered that data presented in stage 2 of the research can be described as a hybrid between subjectivity and objectivity. The foundation and definition of the behaviour was based on subjective observations; the observed behaviours were then identified using an objective approach.

Application of statistics to a hybrid data-set

Statistical analysis is typically applied to quantitative data. It is often considered essential in order to draw meaningful conclusions from the data (Mills et al, 2010). The data within this thesis has many variables including gender, socio-economic background and motivation for attendance. It was therefore deemed useful to highlight key differences between group types so that the reasons for these differences may be understood and contextualised to understand the impact these differences have on the successful participation in classes and adoption of positive behaviours. Statistical analysis was applied to the data from phase 2 of this research to show the significant differences between group types.

The subjective foundation of the data would indicate that the application of statistics to this data-set was unsuitable. However, the steps taken to reduce subjectivity after phase 1 of the research and the preparation of a tally-checklist alongside a clear description of how to identify common behaviours transformed the data into what could be argued to be a subjective-objective hybrid. This made it feasible to apply statistical analysis to understand the occurrences of behaviours to a limited extent.

Furthermore, in order to limit the risk of an unearned sense of scientific rigour that statistical analysis can add to a study it was made clear that the statistical analysis only showed differences between the observation of behaviour between group types and was not used to indicate likelihood of the behaviour occurring at all. The difference between the groups was based only on the observations in phase 2 of the research. The statistical analysis only highlighted that if these behaviours do occur they are most likely to occur in type A workshop rather than type D etc. It therefore indicates *a cause for differences* rather than indicating the chances of something happening.

Subsection conclusion

Subjectivity in research has growing support and it is considered valuable in gaining knowledge about phenomena that are otherwise difficult to understand. Furthermore, the application of the scientific method to a subjective data-set could be considered dubious and unrepresentative of the true rigour of the research. However, the field of maker-based research is relatively young and requires a foundation of empirical research so that it may be validated and valued within the practical applications of these types of studies. In order to 'square this circle' this study used a subjective approach in phase 1 of this research before scrutinising the initial data-set to ensure that observations taken forward for further research could be identified objectively, using a simple description. The second phase of research used a tally-checklist which is a quantitative research method which allowed for both an interpretative analysis as well as a statistical analysis to be carried out. The interpretative analysis proposed the likelihood of the identified behaviour occurring while the statistical analysis highlighted the differences in observed numbers in group types which allowed for an interpretation of why the differences between groups had occurred.

3.10 Rationale for methodology based decision making

The non-linear application of a Grounded Theory methodology can lead to the direction of research and analysis appearing unclear and at time ambiguous. This section aims to clarify what decisions were made and will provide a justification for these. Table 3 at the end of this section provides an overview of these decisions and what options were discarded as a result of the decisions made.

Decision 1- Methodology

The decision to employ Grounded Theory as the methodology for this thesis was made due to the unique position the author found herself in. She was able to draw from a significantly large number of workshops and participants, thus fulfilling the necessity of having a large dataset for using Grounded Theory. Additionally, due to the field of 'children and making' being in its infancy, Grounded Theory provided the opportunity to search within the experiences of children while making and did not rely on the theories and frameworks from other disciplines to design the research. Ethnography or phenomenology were considered as alternative methods and while both would have provided useful and interesting data, it was considered that Grounded Theory would provide a type and amount of data which is rarely available due to the specific requirement necessary to conduct it appropriately and successfully. On reflection it is felt that ethnography or phenomenology may have provided clearer and more succinct findings but that despite the non-linear nature of Grounded Theory it was able to highlight aspects of 'children and their experience while making' which was not anticipated[12].

Decision 2- Reducing mass of data for analysis

From the large amount of data collected from the first stage of workshops the decision was made to select only certain workshop types to take forward. These were 3D printing clubs and youth clubs. 3D printing clubs were selected to take forward as these were organised and facilitated by the researcher which meant that she had greater control over these. This meant that the research was less vulnerable to unpredictable changes by external organisers who may have different priorities. Youth clubs were also chosen to take forward as these workshops offered the opportunity to include a wide cross-section of society and ensured representation of different genders, ethnicities and socio-economic backgrounds.

Decision 3- Differentiating workshop types

The two type of workshops were further broken down into types A, B, C and D. This was done to allow external differences to be taken into account when analysing

[12] An example of this would be the motivation for access to making. This study did not intend or expect to find data which highlighted the need for and possible solutions to understanding accessibility of making. The Grounded Theory methodology and its focus on data influencing the progress of the study, allowed this finding to become apparent.

them. Type A workshops included a returning group of children who were interested in 3D printing. Type B workshops included a group of friends who regularly attended a club after school. Type C workshops took place in a private school. Type D workshops took place in existing youth clubs.

Decision 4- Approach to coding

The decision regarding how to code the data was inspired by Glaser and Strauss (1967) which stipulates that the codes should come from the data. Words, phrases and actions in the diary entries were highlighted.
After the initial stage of coding the codes were condensed into 'potential categories'. This was done using axial coding. Where there were similarities in meaning or outcomes of the relevant events were the same, these codes or relevant events were grouped into potential categories. A description of what each potential category includes in terms of behaviour observation was provided under each 'potential category' Tables 4-19.

Using the 16 categories, a criteria analysis sheet was created to recode the original data. This allowed the data to be searched for within these broader category labels and descriptions. Using the criteria analysis sheet allowed each individual diary entry to be evaluated using the same criterion. This allowed for consistency and therefore additional rigour. Additionally, at this point it was decided that to get a truer overview of the occurrence of particular behaviours in every workshop, only the workshop would be evaluated rather than the participants within the workshop. For example, it did not matter if one or ten participants engaged in problem solving, in both cases the workshop was marked as including problem solving behaviour. This helped to provide a clearer picture of what was happening across workshops. This reduced the vulnerability of the data to being skewed by particularly eventful workshops.

After the criteria analysis sheet was used to recode the data, memos were developed to indicate the number of occurrences of each behaviour alongside initial analysis to understand why the behaviours occurred and in what circumstances to highlight trends in the data.

Decision 5- Choosing categories from 'potential categories'

The process of sorting as described in chapter 2 (section 2.6) was then conducted to decide which potential categories would be taken forward for further analysis. Table 21 highlights the discarded categories with an explanation as to why these were not to be taken forward. The decision was made based on the number of recorded instances of being less than 50% or because to understand the behaviour in context would require further, more specifically designed research which fell outwith the scope of this study.
The six categories taken forward were selected because they all occurred in 50% or more of the workshops and were considered to be consistently easily identifiable,. Additionally, conclusions could be drawn from these observations without having to do further research.

Decision 6- Including phase 7, the verification stage of Grounded Theory

Table 1 highlights the differences between common approaches to Grounded Theory. This thesis used all possible phases including the controversial phase 7, 'checking findings against quantitative research'[13]. Having access to and the ability to conduct hundreds of workshops presented the opportunity to present empirical data which is lacking in this field of research. Despite the associated controversies of the validity of quantitative research on human behaviours (Charmaz, 2014), it was considered important to explore this area. Largely because quantitative data is more effective for the purposes of securing funding by clearly demonstrating experienced benefits and return on investment (Fischer & Miller, 2017).

Decision 7- Applying statistical analysis

[13] The controversy of phase 7 is discussed further in chapter 2. Straussian and Charmazian approaches to Grounded Theory disregard the need for verification by quantitative research (Strauss & Corbin, 1990; Charmaz, 2014) . They argue that by employing phase 7 as described in Table 1 that the value of the qualitative data is reduced, privileging quantitative data instead and therefore rejecting the principles of Grounded Theory (ibid). While the author of this thesis recognises this dilemma, this thesis is written for practitioners and is not a conceptual or theoretical piece. In reality, verification provides data which can be used to calculate returns on investment and as such in practical application, verification research adds value to the data-set.

The decision to conduct statistical analysis on the data collected in the second stage of research was done in order to understand the differences between group types. Until that point analysis had been conducted only on the individual behaviours and workshops. Statistical analysis provided the opportunity to see the more foundational differences between workshop types and what impact the types were having on the observation of specific behaviours. With a data-set that could be described as subjective, the application of statistics could be dismissed or considered uninformative. However, the statistical analysis was beneficial in understanding the differences in group types and despite the contention over the subjectivity of data, statistical analysis highlighted key differences that would be otherwise difficult to identify.

Decisions made	What the decision was and why	Discarded options
Why Grounded Theory?	Grounded theory was an appropriate methodology as it allowed the author to conduct original research in a new area of study without theoretical bias necessary using an alternative approach.	Alternative methodologies options such as ethnography and phenomenology were discarded as the author felt that Grounded Theory was more suitable to her unique circumstances regarding an extensive data set.
Which data should be analysed?	The data set was too large to analyse in its entirety. The decision was made to analyse diary entries from weekly 3D printing clubs and workshops in youth clubs. This offered a wide cross section of society in terms of gender, ethnicity and socio- economic background.	Diary entries from the following types of workshop were not taken forward for further analysis due to being less representative than the chosen workshops. These were: • Birthday parties • Holiday workshops • Faires • Private tuition sessions
How can the workshops be differentiated?	To understand differences between workshops the data was	

	broken into 4 types. Workshop, A, B, C and D. This allowed for mean age, environment, gender and socio-economic background to be analysed more closely to highlight the impact this was having on participants.	
How should the data be coded?	The employed coding method included line-by- line and axial coding. The data was then recoded once codes had been identified within the data which led to 71 'relevant events.. Codes were' then grouped by theme to identify 16 'potential categories' to take forward for further analysis.	The coding method is consistent with most Grounded Theories studies but another option could have been a qualitative data analysis software. This was discarded both because it would be atypical of a Grounded Theory method to use this approach and also due to the diary entries being written over an 18 month period which meant that words and phrases use could change over that period of time and therefore lead to challenges regarding keywords.
Choosing categories from 'potential categories'	6 categories were chosen from the potential categories. These were chosen as they described events which occurred in 50% or more of the documented workshops and did not require additional research to draw conclusions.	The 'potential categories' which were discarded at this stage were: • Fulfilling and enjoyable activity for children • Engages child's focus • Experience of personal capacity • Project planning • Interdisciplinarity of technologies • Freer communication when making • Experience of amazement • Provision of guide increases engagement • Opportunity for teamwork • Interest in the production of weapons The detailed explanation regarding why these were discarded can be found in Table 21.

Inclusion of verification study	A verification study was conducted so that differences between workshop types could be analyses in closer detail with the application of statistical analysis. Additionally, the provision of quantitative data was desirable for an emerging field of research which relies on evidence based findings to support it development and adoption in education.	
How could statistical analysis support data?	Statistical analysis clarified the impact of various factors including workshop environment and socio-economic background of participants on the experiences and exhibited behaviours in workshops.	

Table 3 Methodology based decision making

3.11 Conclusion

This chapter described the methods which were used in this study and explained the interpretation of, and a justification for, using workshops, field notes and diary entries in stage 1 research and tally-checklists in stage 2 research. The ethical considerations and process were then outlined before describing how each of the methods discussed above were applied with regards to organisation, planning, delivery and documentation. A section was included addressing the subjective corpus of data and what impact this has on data analysis and interpretation. Finally, the justification for decisions made regarding the methodology were clarified.

Chapter 4

4.1 Overview

This chapter will detail the number of workshops and participants included in Stage 1 of the research before describing the types of workshops delivered. There will be a short discussion regarding what data to take forward for full analysis. Due to the number of workshops documented deep analysis of some of the data collected was discarded from the scope and length of this study. Therefore, only a portion of the data will be used henceforth. This chapter will then describe and demonstrate each phase of the data analysis, as described in Chapter 2, to produce a small number of 'categories' or 'exhibited behaviours' from which theories will be developed.

4.2 Extent of study

The number of workshops documented was 207 while the total number of participants amounted to 2496. The workshops took place in youth clubs, regular 3D printing clubs, at birthday parties, holiday workshops, faires and private tuition sessions. The break-down of these sessions was as follows:

Workshop	Number of workshops	Number of participants	Boys	Girls	Median age range
Youth Clubs	26	624	314	310	9-12
Regular 3D printing club	121	937	699	238	6-11
Birthday parties	6	59	19	40	7-10
Holiday workshops	30	572	286	286	7-10
Faires	5	473	277	196	4+
Private tuition session	19	68	38	30	10

Table 4 Stage 1 workshop data

As shown in table 4 , the number of each type of workshop varied significantly. However, despite the relatively small number of workshops of both youth clubs and holiday workshops, both had a proportionately large number of participants.

4.2.1 Types of workshop- Stage 1 research, phase 1

This section will describe what each of the types of workshop identified in table 4 are before concluding by explaining which workshops will be taken forward for deep analysis.

Youth clubs

Youth clubs are existing groups where children and young people meet on a regular, usually weekly basis, and socialise under the supervision of trained youth workers. These groups are often council or charity funded and therefore free for the participants to attend. In areas of social deprivation, a hot meal is usually provided for those who attend. Youth clubs can range in size from as few as 12 participants up to more than 100. At the larger clubs there are often several activities that children and young people can engage in including activities such as, boxing, painting, cooking, gaming etc. This description applies to all youth clubs observed within this study.

Regular 3D printing clubs

Regular 3D printing clubs are groups which the researcher-facilitator has established as part of her work. She runs several clubs every week throughout the central belt of Scotland. The regular 3D printing clubs used within this study include one which takes places in the community space within a high school in the suburbs of Edinburgh, one in an arts studio between Edinburgh and Glasgow and one as part of the extra-curricular education programme at a private school in Edinburgh. These regular clubs have returning attendees. These classes cost between £5-£8 to attend.

Birthday parties

3D printing workshops at birthday parties are workshops run for the purpose of a child's birthday celebrations. Children are invited to attend by the 'birthday child' who tends to be very interested in 3D printing. These sessions typically take place in the ‘birthday child’s’ house. It costs the birthday child’s parents £100 to host the party but it is free for guests to attend.

Holiday clubs

3D printing workshops are also delivered at holiday clubs. These are places where parents pay to have their child looked after when schools are closed. Similarly to youth clubs, the 3D printing workshops delivered at holiday clubs are usually one option among many for the children to participate in. These clubs are often very busy: some of them have over 100 children in attendance.

Faires

Faires refer to one off, pop-up events where attendees can buy produce from local craftspeople or makers as well as participate in organised workshops. 3D printing workshops were delivered as part of several faires. Participants paid an entry fee for the faire and then could access any workshop with available places.

Private tuition session

Private tuition refers to a range of special 3D printing workshops arranged for particular children or groups. These sessions usually cost more money and can have as few as 1 participant and usually no more than 5. The private tuition session used in this study included 3D printing pen one-to-one tuition with a child who had delayed motor function. These sessions were used as a form of physiotherapy. Other private tuition sessions were organised for children who were too shy to attend open workshops.

4.3 Scope of study

This study provided the data for a PhD thesis. Therefore, it was not feasible to fully analyse, interpret and produce meaning from 207 workshops. As each workshop had a detailed quantitative data-set as well as diary entries, it was necessary to select only two types of workshop to carry forward for analysis. This decision was made by considering the numbers in table 4.

One type selected to take forward was ‘regular 3D printing workshops’. This choice was made as it has the largest volume of data as 121 workshops were conducted with this type of group and a total of 937 recorded attendances. This makes it one of, if not the biggest, known study of informal maker learning environments where children use 3D printers. This makes it significant as a contribution to maker-based research.

The other type of workshop taken forward was ‘youth club’ based workshops. This was deemed an appropriate choice as youth clubs are places where children and young people from all social and economic backgrounds have free access to the session and as such means that no social group was debarred from representation in this research.

4.3.1 Workshops at regular 3D printing clubs

The workshops delivered at regular 3D printing clubs were numerous and as such it was useful to break this group down further, to understand how each club was run and the circumstances which may have affected behaviour or outcomes. The observation of 3D printing clubs in this study were of three separate groups. These were labelled as ‘Type A’. ‘Type B’ and ‘Type C’. A description of each type is provided below.

Type A

This workshop refers to a regular, usually weekly, 3D printing club attended by a group of unconnected children with a median age of 8 years old. This club takes place in a community room within a high school which none of the participants attended. This is situated in the suburbs of Edinburgh. Children were dropped off by their parents, stayed for one hour and they were free to work on their own projects. Parents paid £5 per week for each child to attend.

Type B

This workshop refers to a regular, usually weekly, 3D printing club attended mainly by one group of friends. The mean age of participants was 10 years old. This club takes place in an art studio in a small village between Edinburgh and Glasgow. The studio is owned by one of the participant's parents. Children came to the club together straight from school, stayed for one hour and worked on whatever they liked. Sometimes parents collected their children from the club but often the children walked home together. Parents paid £5 per week for each child to attend.

Type C

This workshop describes a 3D printing club which takes place in a private school in Edinburgh. The club occurs in a classroom straight after school. The room was the classroom of several of the participants. All participants were based within classrooms in the same corridor as the classroom used for 3D printing workshops. Children stayed for 45 minutes and were collected by parents or school-based childcare. The mean age of participants was 6 years old. Parents paid £8 per week per child and paid 6 months in advance. At the club children could choose what they made with the 3D printing pens. However due to the lack of availability of internet access any files for the 3D printer had to be discussed and organised a week ahead to ensure the files could be downloaded.

4.3.2 3D printing workshops at a youth club

Workshops delivered at youth clubs only amounted to 26 and therefore, this group was not broken down further, but it was labelled as 'Type D' for purposes of analysis. A description of 'Type D' workshops is provided below.

Type D

This workshop describes 3D printing sessions which are delivered within an established youth club. These youth clubs can be council or charity funded and are usually free for participants to attend. Most clubs offer children a free hot meal as well as an activity. 3D printing is booked in as a special treat for young people. Most workshops recorded in this data involved different children in each session and so the activity was usually new to them. The age range varied from session to session but were within the range of 6-18 years old.

4.4 Phases of Grounded Theory research in this study

4.4.1 Phase 1: Data collection

The data collection was completed for all 207 workshops through means of observation, field notes and diary entries as described in Chapter 3. The two types of workshop to be analysed were 'regular 3D printing workshops' and 'youth clubs'.

4.4.2 Phase 2: Note taking

The diary entries and recorded quantitative data was read and notes taken alongside each entry to provide an initial overview before the commencement of coding.

4.4.3 Phase 3: Coding

The diary entries were read closely by using the line-by-line method as suggested by Charmaz (2013), and open-codes were applied, as described by Glaser (1978). These codes will be referred to as 'relevant events' in the next section as this was the label used during analysis to highlight which behaviours or events were relevant for this study[14].

Once these codes were applied, Table 5 was created to chart each 'relevant event' and to track which types of workshops they applied to. The table is shown below and is organised into four distinct workshop types as explained in section 4.3.2. Where available, a reference to images depicting the 'relevant events' are provided. These images are presented in Chapter 8, which provides a visual summary of this thesis. Image titles do not necessarily match the visual summary but provide illustration of the events.

Relevant event	A	B	C	D
Unsure of art ability	1			
Interest inspired conversation	2			
Quiet and focussed	23	4	2	7
3D printing weapons	5	2	1	3

[14] This was determined by searching the data for verbs which indicated that something had happened.

Educational value	1	1	4	1
Happy with creation	24	19	8	12
Want to spend longer at 3D printing	3	4		1
Frustrated but persevered	10	6	6	7
Really enjoyed it	1	1		
Misconception- drawing in printer	1		1	1
Enthusiastic about making	6	4	1	1
Offered advice to others	10		2	3
Innovative idea about using the tech	5	3		1
Wanted to show others what they had made	13	6	3	3
Integration of 3D printer and pen	4	10	3	
Asked for advice	3	1		
Illustrated story with pen while talking. Literally making the narrative.	5	2	1	
Discussion about common hobbies	2			
Wanted to show creation to parent	5	8	4	1
Pens allowed for more creativity	1			
Chattier while making	7	8		1
Less shy when friend is present	1			
	1			1

Want to show others how it works				
Useful solution to problem	1			
Reluctance to try alone			1	
Increased confidence in own ability	1			
3D pens allow for drawing as you think.	1			
Interest inspired making and conversation	21	15	6	6
Response to praise	13	6	3	4
Exploration in CAD	1	5	1	
Intentional design in CAD	1	1		
Longer term project	13	11		2
Enjoy explaining to others	1			
Iterative process	14	7	3	4
Amazed by printer	3	3	1	3
Disappointed with CAD model		1		
Amazed that they made something REAL.	1	1	3	
Peer praise	8	2		3
Environment inspired conversation	4	7	2	
Environment inspired making	7	8	3	
Disjunct between printer and software	1			
Self-identified as feeling good when making.	3	2	1	

Using 3D printer to solve problems.		1		
Templates	3	8	5	1
Parent/responsible adult comment on child's focus	4	1		1
Comment on surprise at girl attending		1		
Appreciation of homemade aesthetic	1	3		
Making for someone else	21	16	7	7
Personal discussion about feelings	1	4	1	1
Making inappropriate body parts				4
Freedom/enjoyed choice	2	1	1	
Child business idea		1		
Imitation making	9	13	5	3
Imaginative play		1	1	
Favourite time of the week	4	1		
Planned makes in advance of class	1	4		
Practice makes perfect	1		4	5
Soothing effect	1			
Fluid about categorisation		3	2	
Co-operative making		2	1	2
Competitive making		1		
Group conversation	3			
Peer inspiration	1	2	1	1

Feeling lost at end of project	1			
Requires encouragement			1	
Digital media cross-over	1	4		
Expression of gratitude	1		2	
Wrecked model as unhappy with it			1	
Chattier when researcher-facilitator joins in	1	1		1
Positive response to error			1	
Proud of making something alone.	1	2	4	2

Table 5 Identified relevant events and occurrences in different workshop types

Table 5 shows that there were 71 'relevant events' within that data. Some of the 'relevant events' only occurred once and so were not taken forward in this thesis. However, by using the next phase of the Grounded Theory methodology it was possible to group these relevant events into memos or 'potential categories'. The researcher labelled these during analysis to highlight for future consideration.

Before the memo-ing process is shown from section 4.4.5, each 'relevant event' and its significance will be described below. This will help to illustrate why these events have been deemed significant. These descriptions will be displayed alongside the relevant line of Table 5 for ease of understanding.

4.4.4 Description of relevant events

Unsure of art ability

This refers to times when children said that they are not good at drawing or art. During the 3D printing sessions this was a comment in response to the children thinking that the activity was an art or craft.

Unsure of art ability	1			

Interest inspired conversation

Interest inspired conversation refers to when the conversation between participants or groups revolved around their interests, these could range from Lego to computer games to sports.

Interest inspired conversation	2			

Quiet and focussed

While using 3D printing pens children often became quiet and focused on their individual models or projects. This was identified in the data by researcher observations and parent comments about the quietness and focus of individual and groups of children.

Quiet and focussed	23	4	2	7

3D printing weapons

This 'relevant event' refers to both the discussion between participants of the feasibility of 3D printing guns and other weapons and the making of toy weapons such as guns and cross-bows (see Figure 26).

3D printing weapons	5	2	1	3

Educational value

This refers to instances where children used the 3D printer or 3D printing pen to demonstrate something that they had learned to other children. This was also used to denote occasions where children learned something about the process of 3D printing and demonstrated this knowledge using the 3D printing pen (see Figure 42).

Educational value	1	1	4	1

Happy with creation

This refers to notes on when children were happy with what they made either with the 3D printer or the 3D printing pen. This was identified by smiles or by verbal confirmation from the child that they were happy with what they had made (see Figures 43-48).

Happy with creation	24	19	8	12

Want to spend longer at 3D printing

This refers to the times where children commented that they did not want the session to end or that they wanted to do it forever.

Want to spend longer at 3D printing	3	4		1

Frustrated but persevered

When using a 3D printing pen, it can be difficult to achieve satisfactory results until enough experience is gained to allow for the anticipation and correction of the extrusion of the plastic. This category refers to instances where children commented or acted in a way that suggested that they were struggling or frustrated with the pen but achieved some sort of success by the end of the session (See figure 36).

Frustrated but persevered	10	6	6	7

Really enjoyed it

This refers to times when children or parents commented that the participant had a good time at the session (see Figures 57-62).

Really enjoyed it	1	1		

Misconception- drawing in printer

A regular misconception was observed when using the 3D printer and 3D printing pens in the same session. Many participants believed that the drawing they created with the 3D printing pen goes into the 3D printer to be 'finished off'. This illustrates a misunderstanding of how the printer works. Another misconception common to young children was that the printer makes the model from a drawing on the side of the printer. The 3D printers used in the sessions were Ultimakers which have a vinyl sticker of the Ultimaker robot on the side of the printer. In introductory sessions the sample print on the printer was often the Ultimaker robot. This led to an assumption that the printer was simply copying the image of the robot from the side and creating it using plastic.

	1		1	1

Misconception- drawing in printer				

Enthusiastic about making

This refers to instances where a child acknowledged verbally or by an excited facial expression that they wanted to get started immediately. This typically occurred during a demonstration of the 3D printing pen (see Figure 27).

Enthusiastic about making	6	4	1	1

Offered advice to others

This refers to times when children shared their experience of using the 3D printing pen to suggest how another child may have success with their model when they were having some trouble (see Figure 37).

Offered advice to others	10		2	3

Innovative idea about using the available technology

This refers to instances where children asked questions or made comments which proposed an alternative way of using the 3D printer or 3D printing pens. This included the type of material to put into the pen and used for the tools.

Innovative idea about using the tech	5	3		1

Wanted to show others what they had made

When a child made something that they are happy with or surprised by they often wanted to show other people what they had made. This ‘relevant event’ categorises ‘others’ as either the session facilitator or other peer participants in the group.

Wanted to show others what they had made	13	6	3	3

Integration of 3D printer and pen

This refers to instances where participants used a 3D printing pen to customise their model which was made with the 3D printer. It also refers to times where children used the process of the 3D printer (e.g. layering, honeycomb infill etc.) to make better models using the 3D printing pen (see Figure 55).

Integration of 3D printer and pen	4	10	3	

Asked for advice

This refers to instances where children asked for advice on how to improve their model rather than asking for the researcher-facilitator to do something for them.

Asked for advice	3	1		

Illustrated story with pen while talking.

This refers to instances where children had been describing something or telling a story and when they felt they were not conveying the visual description well they used the 3D printing pens to either make a prop to help them in their description or to make a small representation of the story and drew as they talked. They were literally making the narrative.

Illustrated story with pen while talking.	5	2	1	

Discussion about common hobbies

This refers to times where children engaged with other children when they discovered that they shared common hobbies such as swimming or learning Spanish.

Discussion about common hobbies	2			

Wanted to show creation to parent

This refers to times where children verbalised their desire to show their model to their parent or when at the end of the session, they enthusiastically showed a parent what they had made. This was recognised as a distinct 'relevant event' from *Wanted to show others what they had made,* because there may be differences between desire for peer and parent approval.

Wanted to show creation to parent	5	8	4	1

Pens allowed for more creativity

This refers to comments from children who acknowledged their preference for the 3D printing pen over the 3D printer with the justification that the 3D printing pens allowed them more freedom over what and how they made their model (see Figure 44).

Pens allowed for more creativity	1			

Chattier while making

This refers to the researcher's observations of times when children become more talkative when they started making something. It typically indicated a transformation in how the child was behaving before they started making and during the making process (see Figure 37).

Chattier while making	7	8		1

Less shy when friend is present

This refers to instances where a child who had participated in several sessions became more outgoing when they brought a friend along to the session.

Less shy when friend is present	1			

Want to show others how it works

It was observed that children who had previously participated in a session enjoyed taking responsibility for enthusing and teaching other participants how to use the 3D printing pen. This was identified where a child asked the facilitator if they could be the one to explain and where the researcher has observed children taking initiative to explain without the researcher-facilitator's support.

Want to show others how it works	1			1

Useful solution to the problem

This refers to times where children made something that solves a problem in their lives.

Useful solution to problem	1			

Reluctance to try alone

As described previously, using a 3D printing pen requires patience and practice. Some children became easily dissatisfied and felt that they could not make the pen work without the help of the researcher-facilitator. This refers to times where children asked for help.

Reluctance to try alone			1	

Increased confidence in own ability

As above, to achieve successful operation of the 3D printing pen requires patience and practice which leads to a transformation in skills. Children can achieve a good level of skill in using the 3D printing pen in a relatively short period of time. Therefore, they can experience their own capacity in a tangible way.

Increased confidence in own ability	1			

3D pens allow for drawing as you think

This refers to participant comments which described the positive aspects of using a 3D printing pen which are that they allow users to visually convey ideas and concepts which might otherwise be difficult to do.

3D pens allow for drawing as you think.	1			

Interest inspired making and conversation

This refers to instances where children have made something as a result of an interest that they have. This can range from super-heroes, to fidget spinners. These are times where the creation could be linked back to something the child had shown interest in (see Figure 70).

	21	15	6	6

Interest inspired making and conversation				

Response to praise

This refers to times where children responded positively to praise. The researcher-facilitator gave praise to children when they were overcoming their frustration or created something well or to a high standard. The response to praise was largely measured in the facial expression of a child when they receive praise (see Figure 59). Their happiness response to praise was categorised by a smile.

Response to praise	13	6	3	4

Exploration of CAD

This refers to instances where a child used CAD in an explorative way when they had no defined objective of what they hoped to achieve and instead played with the tools available to them.

Exploration in CAD	1	5	1	

Intentional design in CAD

This refers to the times where a child started using CAD to make a preconceived design. They used the tools which they thought would help them create their desired outcome.

Intentional design in CAD	1	1		

Longer term project

This refers to observations of children who were working on a project which lasted more than one session. This was indicated by them taking their work-in-progress model home and bringing it back in subsequent weeks to continue working on it.

Longer term project	13	11		2

Enjoy explaining to others

This refers to times where children showed a desire to explain how the 3D printer and 3D printing pens work to new participants.

	1			

Enjoy explaining to others				

Iterative process

This refers to behaviour observed by the researcher-facilitator when children were in the process of making something, tested the design and then went back to make changes to make the design more successful. This process of iteration was identified by the researcher when a child made three or more changes to their design in order to achieve a more successful design.

Iterative process	14	7	3	4

Amazed by printer

This refers to instances when children acknowledged their amazement with the 3D printer by saying 'Ahhh' or 'wow' or 'that's amazing' etc. (see Figure 28).

Amazed by printer	3	3	1	3

Disappointed with CAD model

This refers to times where a child was dissatisfied with their model which they designed using CAD and made on the 3D printer. In the initial learning stages of using CAD the output often does not match the expectation.

Disappointed with CAD model		1		

Amazed that they made something <u>real</u>

This refers to times where a child verbally acknowledged that they were pleased or surprised that they managed to make something which they described as 'real'. This was evident when they produced something which they deemed was of a high enough quality that one would buy it or if they incorporated a manufactured product into their design such as a keyring (see Figure 53).

Amazed that they made something REAL.	1	1	3	

Peer praise

This refers to the times where children praised other children. This was identified by the researcher-facilitator when children commented that they liked or showed that they were impressed by the creation of another child. This invoked a positive response in the child whose work was praised and could be associated with an increase in social confidence.

Peer praise	8	2		3

Environment inspired conversation

This referred to instances where children spoke about things that were happening around them, happened during the day or was happening culturally- special holidays etc.

Environment inspired conversation	4	7	2	

Environment inspired making

This refers to instances where children made something in response or related to something that happened to them, their day or something that was happening culturally, for example Christmas.

Environment inspired making	7	8	3	

Disjunct between software and printer

This relevant event refers to instances where participants were not directly appreciating the complexity of what they wanted to produce. This demonstrates a lack of comprehension regarding the parameters of a physical object or a disregard for the consideration of material use.

Disjunct between printer and software	1			

Self-identified as feeling good when making

This refers to instances when participants verbally described themselves as happy while in the process of making and when they retrospectively described making as something that made them feel good.

Self-identified as feeling good when making.	3	2	1	

Using a 3D printer to solve problems

This refers to instances where children considered how a 3D printer or 3D printing pen could be used to solve problems in their immediate environment. For example, in response to a child not having access to utensils for eating, a child created a fork with the 3D printing pen.

Using 3D printer to solve problems.		1		

Templates

This refers to workshops where children were observed making use of templates or guide while using 3D printing pens or CAD software. These were introduced to workshops as a way of engaging children who were easily frustrated by the 3D printing pen. The templates and guides helped to provide a focus and goal for the participants to work towards (see Figure 29).

Templates	3	8	5	1

Parent/responsible adult comment on child's focus

Parents and support workers made comments on how quiet and focussed their children were during the 3D printing workshop. Many instances of this observation described parents as talking about a transformation in their child compared to how they usually behave.

Parent/responsible adult comment on child's focus	4	1		1

Comment on surprise at girl attending

This refers to situations in the sessions which were mainly attended by boys who were surprised when a girl attended.

Comment on surprise at girl attending		1		

Appreciation of the hand-made aesthetic

The finish that a 3D printing pen gives is not neat and therefore things made with the 3D printing pens usually look hand-made (see Figure 39). Situations were children said that they liked the look of it or instances where they adapted a manufactured object to have the finish of a 3D printing pen object were considered as indications that children liked the look of the 3D printing pen finish.

Appreciation of homemade aesthetic	1	3		

Making for someone else

This refers to times when a participant made something for someone else. This was usually identified as having occurred when a child said that they were going to make or had made something for someone else. However, where a child did not verbally confirm this, the customisation of an object with a name that did not belong to the child was also taken as evidence that the child had made an object for someone else.

Making for someone else	21	16	7	7

Personal discussion about feelings

This refers to situations were children and young people spoke about how they were feeling and any problems they were having at home or school while they were making something with the 3D printing pen.

Personal discussion about feelings	1	4	1	1

Making "inappropriate" body parts

This refers to instances when young people made body parts which may not be considered suitable for this particular environment. For example, penises. These were not necessarily inappropriate in and of themselves but in the context of these workshops they were made in the same way a young person might draw a penis on their jotter.

Making inappropriate body parts				4

Enjoy the freedom and choice while making

This refers to times where children verbally said that they enjoyed having the free choice of colour and creation. It additionally referred to instances where children felt they had agency to be able to make something for someone. This may be interpreted as feeling that this gave them some control and responsibility over the situation, where otherwise they may have felt helpless. For example, when a grandmother was ill, and the grandchild was glad he could do something besides making a card that could really make his granny feel better (See figure 52).

Freedom/enjoyed choice	2	1	1	

Child business idea

This refers to times when a child identified potential in something they were making to turn it into a commercial venture which would allow them to create more and sell them to others (see Figure 54).

Child business idea		1		

Imitation making

This refers to times where children made something because someone else in the same session as them, was also making it. This usually involved peer imitation however, at times it applied to imitation of the research-facilitator.

Imitation making	9	13	5	3

Imaginative play

This refers to instances where children used the 3D printing pen to demonstrate a prop in a story or idea and then continued to use it in imaginative scenarios. For example, a fishing rod and then continuing to pretend that they were fishing (see Figure 45).

Imaginative play		1	1	

Favourite time of the week

This refers to the comments, of both participants and parents, who said that the 3D printing session is the best time in the week or that they looked forward to it all week.

Favourite time of the week	4	1		

Planned makes in advance of class

This refers to instances were children came to the class with a drawing, plan or set of instructions for what they intended to do (See figure 23). This suggests that the child had been thinking about the class and had considered how he/she should use their time to create something that they wanted to make.

Planned makes in advance of class	1	4		

Practice makes perfect

This refers to times where children used or demonstrated with some description the phrase, 'practice makes perfect'.

Practice makes perfect	1		4	5

Soothing effect

This refers to times where participants or parents commented on the soothing and relaxing effect of using 3D printing pens.

Soothing effect	1			

Fluid about the categorisation of creations

This refers to times where children were accepting of a change in how they or someone else described their make. For example, a child may have started out drawing a rhino and then another child said, 'great dog- it's so cute' and the first child then confirmed that it was indeed a dog and not a rhino. The categorisation of this 'relevant event' was made where children had verbally described their creation and then changed the label or name of their creation in response to someone else's interpretation.

Fluid about categorisation		3	2	

Co-operative making

This refers to instances where children worked together with other children, in pairs or in groups of up to 12 to create something together.

Co-operative making		2	1	2

Competitive making

This refers to instances where children challenged each other to make things and then had a discussion to decide who had won (see Figure 38).

Competitive making		1		

Group conversation

This refers to instances where children participated in conversation with the whole group of participants. This often started out as a conversation between two children or between a child and the researcher-facilitator and then became a group wide discussion (see Figure 51).

Group conversation	3			

Peer inspiration

This refers to instances where a child made or achieved something in their making process and other children were so impressed by it that they wanted to learn how to do the same or practice a particular skill so that they could accomplish that achievement in the future.

Peer inspiration	1	2	1	1

Feeling lost at end of project

This refers to instances where a child described themselves as feeling lost and directionless once they had finished a longer-term project.

Feeling lost at end of project	1			

Requires encouragement

This refers to times where a child required encouragement to keep trying. Children will often get frustrated or feel that they are not able to use the 3D printing pen in the way they would like to and then ask for help or get upset. In these cases, they required encouragement to keep practicing.

Requires encouragement			1	

Digital media cross-over

This refers to times where there was an intentional cross-over between digital technologies by the participant. For example, this was done when a child wanted to make a video about using a 3D printer (see Figure 17).

Digital media cross-over	1	4		

Expression of gratitude

This refers to times where children or parents said thank you to the researcher-facilitator for the impact that the sessions had on the child. This gratitude was also identified when children made something for the researcher-facilitator and described it as being a gift for helping them.

Expression of gratitude	1		2	

Wrecked model as unhappy with it

This refers to times where children destroyed the model they were making because they were unhappy with it.

Wrecked model as unhappy with it			1	

Chattier when researcher-facilitator joined in

This relevant event described the scenario where the children became more open and talked more in comparison to the time prior to the researcher-facilitator joining in and using a 3D printing pen alongside the rest of the group.

Chattier when researcher-facilitator joined in	1	1		1

Positive response to error

This refers to times where a child made a mistake but did not show any negative reaction and instead explained what they learned from the mistake or what they planned to do next to avoid making the mistake again.

Positive response to error			1	

Proud of making something alone

This refers to instances where a child verbally said to the researcher-facilitator or a parent that they made the model by themselves with an emphasis on having achieved it themselves. This expression of pride often came after a requirement for encouragement and reassurance. This perhaps bestows value on the act of achieving something independently rather than with the support of an authority. Additionally, this would be evidence of the child's own capacity (see Figure 43).

Proud of making something alone.	1	2	4	2

4.4.5 Phase 4: Memo-ing

This section will describe how the 71 'relevant events' described in the previous section (4.4.4) were condensed through the process of memo-ing. Memo-ing is described by Glaser (1978) as, 'the core stage in the process of generating theory, the bedrock of theory generation' (Glaser, 1978: 83) This is the stage where ideas should develop in response to the data and meaning should begin to emerge (Jones & Alony, 2011).

This process was started by considering the 'relevant events' in terms of similarity to each other. In cases where the same phenomena could explain both events, these were combined under a core label to become potential categories. Additionally, when the process of memo-ing was deemed complete any 'relevant events' or newly defined 'potential categories' which amounted to fewer than 6 instances then these were discarded as this was deemed too few to ascertain any significant meaning from. However, due to the organic and constructivist nature of this study the absence of observation notes of a particular event did not mean that the event did not happen, it simply meant that the researcher-facilitator did not record it in the diary entry after the session. The researcher-facilitator was not looking for anything in particular when facilitating these workshops and therefore events which now seem interesting as they have occurred repeatedly, did not necessarily appear interesting or relevant at the time of recording. This is why it was important to consider events which not appearing in great numbers throughout the observations, could not be assumed to have not occurred more often than the data showed. Those events which did occur less than six times may still be of interest for further study but are considered to be beyond the scope of this study.

The details regarding the two stages of condensing are detailed below.

4.4.6 Condensing potential categories based on similarity

Below, the potential categories have been grouped into single categories, to take forward into the next stage of analysis, alongside a short description of why the 'relevant events' were grouped together.

Category 1

Relevant event	A	B	C	D	Total
Using 3D printer to solve problems		1			1
Frustrated but persevered	10	6	6	7	29
Asked for advice	3	1			4
Iterative process	14	7	3	4	28
Positive response to error			1		1
Fluid about categorisation		3	2		5
Offered advice to others	10		2	3	15
Practice makes perfect	1		4	5	10
Exploration in CAD	1	5	1		7
					100

Table 6 Problem solving behaviours

The relevant events in Table 6 were condensed into a category labelled '**Problem solving**' as each individual event involved skills required or useful to solve problems.

Category 2

Relevant event	A	B	C	D	Total
Self-identified as feeling good when making	3	2	1	1	7
Enthusiastic about making	6	4	1	1	12
Really enjoyed it	1	1			2
Wanted to spend longer at 3D printing	3	4		1	8
Favourite time of the week	4	1			5
					34

Table 7 Observed behaviours show that the activity is fulfilling and enjoyable for children

The relevant events in Table 7 were condensed into a category labelled '**Fulfilling and enjoyable activity for children**'. Each event listed above were a result of finding the 3D printing session enjoyable and fulfilling.

Category 3

Relevant event	A	B	C	D	Total
Discussion about common hobbies	2				2
Interest inspired making and conversation	21	15	6	6	48
Interest inspired conversation	2				2
Environment inspired conversation	7	8	3		18
Environment inspired making	4	7	2		13
Personal discussion about feelings	1	4	1	1	7
Group conversation	3				3
Illustrated story with 3D printing pen while talking. Literally making the narrative.	5	2	1		8
Imaginative play		1	1		2
					103

Table 8 Opportunity to communicate with peers and themselves

The relevant events included in Table 8 were combined into a category labelled as '**Opportunity to communicate with peers about themselves**'. This was deemed appropriate as each event involved a child sharing something about themselves or their experiences with a wider group.

Category 4

Relevant event	A	B	C	D	Total
Peer praise	8	2		3	13
Response to praise	13	6	3	4	26
Wanted to show others what they had made	13	6	3	3	25
Wanted to show creation to parent	5	8	4	1	18
					82

Table 9 Behaviour showing an expression of pride in achievement

The relevant events described in Table 9 (above) were condensed into a category labelled as '**Proud of what they achieved**'. This was a suitable label for these events as they all lead to or were caused by a feeling of pride in what was achieved. These events could be considered as individual events in a study with a wider scope as the responses to different categories of people would be an interesting phenomenon to research further.

Category 5

Relevant event	A	B	C	D	Total
Quiet and focussed	23	4	2	7	36
Parent/responsible adult comment on child's focus	4	1		1	6
Soothing effect	1				1
					43

Table 10 Behaviour indicating engaged focus

The relevant events in Table 10 were categorised as '**Engages a child's focus**'. Each event refers to the behaviour of children as they use a 3D printing pen and shows that children will often become quiet and focussed on their activity while using the 3D printing pen.

Category 6

Relevant event	A	B	C	D	Total
Amazed that they made something real	1	1	3		5
Freedom/enjoyed choice	2	1	1		4
Making for someone else	21	16	7	7	51
Appreciation of the handmade	1	3			4
					64

Table 11 Observed experiences of agency

The relevant events shown in Table 11 were combined into a category called '**Experience of agency**'. These events contributed to a child sense of capacity and responsibility. In the context of this study these events were also closely related to a sense of generosity and so the agency described should be considered with this in mind.

Category 7

Relevant event	A	B	C	D	Total
Unsure of art ability	1				1
Requires encouragement			1		1
Reluctance to try alone			1		1
Increased confidence in own ability	1				1
Proud of making something alone	1	2	4	2	9
					13

Table 12 Behaviours showing experience of personal capacity

The relevant events shown in Table 12 were combined into a category called '**Experience of personal capacity**'. This was an appropriate label as each event contributed to the transformation of a child from feeling unable to achieve a particular task to being able to complete it and being proud that they had.

Category 8

Relevant event	A	B	C	D	Total
Longer term project	13	11		2	26

Planned makes in advance of class	1	4			5
Useful solution to problem	1				1
Intentional design in CAD	1	1			2
					34

Table 13 Observations of project planning

The relevant events in Table 13 were combined into a category called '**Project planning**'. This was an appropriate category name as each event required some planning for future creation.

Category 9

Relevant events	A	B	C	D	Total
Misconception of how the 3D printer and 3D printing pen works	1		1	1	3
Disjunct between printer and software	1				1
Educational value	1	1	4	1	7
Peer inspiration	1	2	1	1	5
Imitation making	9	13	5	3	30
					46

Table 14 Social learning behaviours

The relevant events included in Table 14 were categorised as '**Social learning**'. This was considered a relevant category name as each event indicates when learning occurred either by making mistakes which were corrected or by being inspired or copying someone else in the same group.

Category 10

Relevant event	A	B	C	D	Total
Integration of 3D printer and 3D printing pen	4	10	3		17
Innovative idea about using the available technology	5	3		1	9
Digital media cross-over	1	4			5
					31

Table 15 Interest shown in the interdisciplinarity of technology

The relevant events which appear in Table 15 were categorised under the heading, '**Interdisciplinarity of technology**'. These events refer to times where children considered how 3D printing technologies could be used together and with other technologies to creatively produce another object or file.

Category 11

Relevant event	A	B	C	D	Total
Happy with creation	24	19	8	12	63
					63

Table 16 Expression of satisfaction with outcome

The relevant event shown in Table 16 was categorised as '**Satisfaction with outcome**'. This event was extrapolated out to include all outcomes of workshops which the participants were happy with.

Category 12

Relevant event	A	B	C	D	Total
Chattier while making	7	8		1	16
					16

Table 17 Observation of freer communication when making

The relevant event described in Table 17 was categorised as '**Freer communication when making**'. This encompassed all relevant events which indicate a transformation to more communication when engaged in the making process.

Category 13

Relevant event	A	B	C	D	Total
Amazed by printer	3	3	1	3	10
					10

Table 18 Amazement expressed by participants

The relevant event indicated in Table 18 was categorised as '**Experience of amazement**'. This included all instances where participants were very impressed by something they saw or did during a workshop.

Category 14

Relevant event	A	B	C	D	Total
Templates	3	8	5	1	17
					17

Table 19 Provision of guide increased engagement

For categorisation this relevant event has been described as '**Provision of guide increases engagement**'. This means that this category covers all instances where a participant better engaged with a session when given additional guidance in the form of printouts or clear instructions.

Category 15

Relevant event	A	B	C	D	Total
Co-operative making		2	1	2	5
					5

Table 20 Observed opportunities for team-work

The categorisation of the relevant event in Table 20 is '**Opportunity for team-work'**. This included all instances where participants took the opportunity to work together.

Category16

Relevant event	A	B	C	D	Total
3D printing weapons	5	2	1	3	11
					11

Table 21 Interest in production of weapons

The relevant event shown in table 21 was categorised as '**Interest in production of weapons**'. This included instances where children asked if they could 3D print guns as well as times where participants made toy weapons with the 3D printing pens and 3D printer.

4.5 Analysis stage 2

Once the 'relevant events' were condensed into fewer 'potential categories' through the process of memo-ing, these were then put into a criteria analysis sheet (See appendix 5). This was used to re-evaluate all of the diary entries. This second round of analysis allowed the data to be considered as a whole and using the criteria analysis sheet, each entry could be analysed by the same criterion. Additionally, in this round of analysis instead of each occurrence of a particular category being noted, each workshop in which a category occurred was noted instead. This allowed for a fairer overview of the workshop. The previous method of analysis was merely looking for common behaviours. However, if one workshop was noted as having the same behaviour repeated throughout by different participants, it could skew the data to suggest that this behaviour was common across workshops when it could simply be common in a few workshops. It was hoped this would improve the representativeness.

The data below has also been split across four segments to allow for cross analysis in the next chapter. The number of workshops in which particular categories occurred is listed individually per type of workshop. A total figure is shown in the left column.

Criteria analysis sheet- existing data: Results

Category	A	B	C	D
Problem solving Total: 72	24	21	14	13

Social Learning Total: 56	16	20	11	9
Fulfilling and enjoyable activity for children Total: 31	15	10	2	4
Interdisciplinarity of technologies Total: 26	11	13	1	1
Proud of achievement Total: 62	24	18	10	10
Opportunity to communicate with peers about themselves Total: 76	34	26	9	7
Engages a child's focus Total: 32	17	7	2	6
Experience of agency Total: 59	24	18	10	7
Experience of personal capacity Total: 36	15	6	8	7
Project planning Total: 28	12	14		2

Satisfaction with outcome Total: 54	21	18	7	8
Opportunity for teamwork Total: 8	2	3	1	2
Interest in production of weapons using 3D printing technology Total: 11	6	3	1	1
Freer communication when making Total: 26	12	10	1	3
Experience of amazement Total: 17	5	6	2	4
Provision of guide increases engagement Total: 19	4	9	5	1

Table 22 Total observations of potential categories

Table 22 shows that the number of workshops of each type which exhibit the identified 'potential categories'. The total number of workshops which exhibit each potential category is highlighted below alongside some initial statements of analysis.

4.5.1 Memos

72 of 148 Workshops demonstrate problem solving

From stage 1 of this research it appears that almost half of all workshop were shown to engage the problem solving skills of the participants, which may be considered a good skill to develop in childhood. This may support 'maker education' as a desirable option for formal and/or extracurricular education.

56 of 148 Workshops demonstrate social learning

Observations from stage 1 research show that in just over one third of 3D printing workshops, children were provided with the opportunity to learn from each other and learn by asking questions of the group. This was considered an essential skill for children by Vygotsky (1930:23). However, one third of workshops is a relatively small portion and so this would benefit from being checked with verification research.

31 of 148 Workshops demonstrate that this is a fulfilling and enjoyable activity for children

Children showed by expression or verbalisation that they found the activity fulfilling and enjoyable in less than one quarter of workshops. This makes this 'potential category' one that cannot be proposed with certainty and therefore was not taken forward. However, it should be noted for future reference that this behaviour is one which is difficult to recognise within a diary entry unless the facilitator-research actively wrote that the children found the activity fulfilling and enjoyable.

26 of 148 Workshops demonstrated the interdisciplinarity of technologies

Participants combined the capacity of different technologies to create new artefacts in few cases in stage 1 research and as such this potential category is unlikely to impact the findings of this study. However, it is an interesting observation and a possible interesting future study with a more structured study design.

62 of 148 Workshops demonstrated pride in achievement

Over one third of workshops showed that participants expressed pride in what they had created. This is an example of behaviour which is unlikely to be identifiable within the diary entries in the absence of a direct statement saying that children were proud and as such the real figure regarding occurrence of this behaviour may be higher. This potential category will benefit from being checked within the verification research.

76 of 148 Workshops demonstrated the opportunity to communicate with peers about themselves

Over half of the observations from stage 1 of this research highlighted that participants had the opportunity to communicate with their peers about themselves. This could be considered a positive aspect of these workshops to improve social skills and self-confidence in educational settings.

32 of 148 Workshops demonstrated that a child's focus was engaged

Less than one quarter of workshops were described as engaging the participants' focus. The data does not overwhelmingly support this claim. However, it is something that would be interesting to explore further in future.

59 of 148 Workshops demonstrated an experience of agency

Over one third of workshops showed that participating in a 3D printing workshop resulted in participants experiencing agency. This is an important experience for children to have so that they have confidence and self-esteem in their own ability and their capacity to change things in both their immediate and wider environment.

36 of 148 Workshops demonstrated experience of personal capacity

This is a similar 'potential category' to the previous one described. However this focuses on the observed transformation of a participant from feeling unable to do something, to realising that they are capable. Experience of personal capacity was shown to occur in fewer than one quarter of workshops but may be an interesting point for further research regarding the empowerment of children.

28 of 148 Workshops demonstrated project planning

Planning may be considered a positive skill to develop (Friedman & Scholnick, 2014: 25). However, relatively few workshops showed that participants engaged in planning and as such it was not taken forward for this study.

54 of 148 Workshops demonstrated satisfaction with outcome

Over one third of workshops were described as resulting in participants being happy with what they made. This may be a ‘potential category’ which would benefit from verification research.

8 of 148 Workshops demonstrated opportunity for teamwork

Few workshops in stage 1 research were conducive to teamwork and as such it was not considered further in the next stage of analysis.

11 of 148Workshops demonstrated interest in the production of weapons using 3D printing technology

Interest in weapons produced using 3D printing technology was relatively rare however, it will be an interesting topic to research further in future as there are no known studies relating to children’s perception of 3D printable weapons.

26 of 148 Workshops demonstrating freer communication when making

This ‘potential category’ did not occur within the data enough times to be considered for the next stage of analysis and would perhaps require a more traditional study design to research this observation effectively.

17 of 148 Workshops demonstrated experience of amazement

The recording of participants exhibiting signs that they were amazed by the 3D printer were relatively rare and as such this will not impact the findings of this study.

19 of 148 Workshops demonstrated that provision of guide increases engagement

The impact of the provision of a guide was something which was not recorded often within the diary entries. However, guides have been used by almost every participant the researcher-facilitator has ever worked with and as such a research question based around the provision of guide would perhaps be necessary to record any meaningful data with regard to this.

4.5.2 Quantitative data

The quantitative data recorded from each workshop will be discussed in the next chapter to understand the influence of different factors on the results. These factors include age range, gender, social environment and motivation for attending.

4.7 Conclusion

This chapter provided an overview of the research conducted and a breakdown of number of workshops, participants and the type of workshops conducted. It was deemed necessary to choose types of workshop to take forward for analysis and these types were then described in detail. 'Relevant events' and 'potential categories' were then derived from the data before initial comments on what the data shows were provided. The next chapter will provide findings from the stage 1 research of this study before outlining the use of a verification study and what its results show.

Chapter 5

5.1 Overview

This chapter leads on from a discussion about the research carried out through to and including phase 4 of the Grounded Theory methodology: memo-ing. This chapter will detail phase 5 through to phase 7: sorting, writing and verification against quantitative research. Therefore, this chapter will be split into three distinct sections, the first will discuss how the remaining data will be sorted, before 'soft' theories are presented based on each finding. The chapter will conclude with findings from the verification research which was carried out in 40 workshops between July 2019 and September 2019.

5.2 Phase 5: Sorting

Considering the Figures referenced and memos relating to the 16 categories as discussed in section 4.4.6 in Chapter 4, some categories will not be taken forward for generating theory. This is because either, there are too few instances of the 'relevant event' taking place to extrapolate significant meaning, or the 'relevant event' would require further research to understand the occurrence within context. Therefore, the categories which will be discarded during the 'sorting' phase are detailed in Table 23 (below), alongside a justification for why they will not be taken forward.

Number	Category not being taken forward	Reason for being discarded
2	Fulfilling and enjoyable activity for children	The fulfilment and enjoyment of children while taking part in a 3D printing workshop was only clear in the observations of less than one quarter of all observations. It means that it cannot be proposed, with certainty, as a behaviour that will be exhibited in 3D printing workshops.

5	Engages child's focus	In terms of self-reflection, it was surprising to discover that observations describing 3D printing workshops as conducive to engaging focus occurred in less than one quarter of workshops. In this case, the data does not support the claim in great enough numbers to take forward. However, it is a topic the researcher-facilitator would like to explore further in future.
7	Experience of personal capacity	The observation of a transformation in a participant's awareness of personal capacity was recorded in less than one quarter of workshops and as such it will not be taken forward in this research. However, this would be an interesting phenomenon, to research further with regards to the empowerment of children.
8	Project planning	Few workshop observations described participants as having engaged in planning and therefore it will not be taken forward to stage 2 research.
10	Interdisciplinarity of technologies	Combining technologies to produce new artefacts, digital or physical was an interesting behaviour observed in 26 workshops. However, this amounts to less than one fifth of total workshops and as such will not be taken forward in this study.
12	Freer communication when making	Communicating more freely while in the process of making was noted in less than one fifth of all workshops and as such will not be taken forward for further research

		in this study. Additionally, the research of this particular, phenomena may require a more traditional research approach to test the hypothesis.
13	Experience of amazement	Few workshop observations commented on the amazement experienced by participants and as such this will not be taken forward to stage 2 of the research.
14	Provision of guide increases engagement	Less than one seventh of all workshop observations describe the use of a guide. However, almost all participants the researcher-facilitator has ever worked with have used guides. This suggests that the use of a guide could not be argued to be contributing to engagement without conducting more studies to test workshops with and without the provision of guides.
15	Opportunity for teamwork	Only 8 workshop observations described the opportunity for teamwork among participants. This ‘potential category’ will therefore not be taken forward to stage 2 of this research.
16	Interest in the production of weapons	There were relatively few instances in the workshop observations which depict participant interest in the production of weapons using 3D printing technology. Therefore, this will not be taken forward to stage 2 of this research, though may be an interesting topic to study in future.

Table 23 Discarded potential categories

The categories which will be taken forward for stage 2 of this research are:

Problem solving, Social learning, Proud of achievement, Opportunity to communicate with peers about themselves, Experience of Agency and Satisfaction with outcome. The next section will provide a short, written statement referring directly to the diary entries (See appendix 3) about each of these 'categories' to form 'soft' theories.

5.3 Phase 6: Writing

This section will provide 'soft' theories based on the 'categories' isolated in the previous section. The number of each type of workshop differed across the study (54 type A, 46 type B, 21 type C and 27 type D) and as such, to be able to compare the numbers it was necessary to transform the data into percentages.

5.3.1 Problem solving

Out of 148 workshops analysed, 72 of them showed evidence that children had engaged in problem solving. This shows that in 49% of 3D printing workshops participants were engaged in problem solving. Workshops which took place in a school setting (type C) showed that engagement with problem solving occurred in 67% of workshops compared to just 44% in a weekly club setting (type A), 46% in a weekly club setting (type B) and 48% in a youth club setting (type D). This shows that workshops in a school setting have a higher chance of engaging children in problem solving.

The use and development of problem-solving skills was noted for just less than half of all Type A workshops. The behaviour tended to be a natural response to a particular problem and did not usually require encouragement to overcome the problem. For example, in one workshop a boy was observed to have exhibited significant perseverance when he could not get his model looking the way he wanted. The diary entry noted:

> *'Today he had a big pile of plastic lines next to him and when I asked him what it was, he said it was his first 13 failures of the afternoon. He said it without any hint of frustration or disappointment. I asked him how he was getting on with it now and he said that he thought it was working now but he might start again if it did not work the way he wanted it to.' (Appendix 3: diary entry 22)*

This indifferent attitude towards failure indicates that this child considers failure as an uninteresting part of the process of making using 3D printing. This suggests that by participating in informal 3D printing workshops it may be possible to instil positive attitudes towards failure which could extend to other parts of their learning experience or life.

The number of Type B workshops which were shown to be conducive to problem solving behaviour were similar to the number of Type A workshops. However, the example below describes an instance where a number of boys were making a 'Pokémon Go launcher' which is a physical frame that clips onto a mobile phone to improve the movement of fingers on a touch screen which facilitates better performance in the game, 'Pokémon Go'.[15]

> *'They started by measuring their phones to make sure their launcher fitted on their phone. They drew out the flat design on paper and then connected it at the sides. A few of the boys did it quickly but their launchers were a bit flimsy. They made another one and made it a lot sturdier and were so pleased with how it looked.' (Appendix 3: diary entry 107)*

This example shows that when children are engaged in making something related to their hobby, which they will find useful. They are willing to make different versions of the same object until they produce one that they are happy with and which works as they intend it to and therefore engage in an iterative learning and making process. This suggests that by relating learning material to an existing interest and using it as an opportunity to allow children to create something which they can physically use, the children are more likely to actively participate in the learning process without conscious effort to do so.

Type C workshops were shown to be the most conducive to problem solving behaviour with two thirds of workshops observed having participants engage in problem solving. Type C workshops took place in a private school setting and the problem solving was often the result of encouragement to work through a problem. The setting could be argued to have impacted the process of overcoming problems as in their school lessons the participants would be expected to keep trying until they

[15] This pokémon go launcher works as a ramp and bumpers do in bowling to help players direct the ball more effectively towards the pins.

were successful. As such, given that the workshops were delivered in a classroom, immediately after school, the participants would likely be behaving as they would in their formal lessons. However, despite this, the freedom allowed within these workshops resulted in participants assessing their own capacity to handle risk with regards to solving an issue. In the following example, a group of girls wanted to make rings and found an innovative technique for doing so.

> *'Three of the girls decided to make rings today. They started out by drawing circles, but one girl realised that they could draw directly onto their fingers because they were wearing gloves. I suggested that it might be hot, but they said they were fine, and it was the best way to get a ring the right size.' (Appendix 3: diary entry 79)*

The above example demonstrates that when given the freedom to decide for themselves, children can consider options and choose one that fits with their desires, capacity and physical ability. If drawing the ring directly onto the gloved finger was too hot as suggested by the researcher-facilitator, the participants would not have been able to tolerate the heat and the 3D printing pen would burn their fingers and they would not continue using the 3D printing pen in this way. However, despite making their fingers feel very hot the participants were able to decide for themselves if it was too hot. This shows that by incorporating making into education, children can develop a scale of risk tolerance which will ensure that they can consider the consequences of their choices and make an informed choice on how much risk is reasonable or appropriate.

Of all type D workshops observed, just less than half showed participants engaging in problem solving. Unlike the other three examples in this category, the example provided below is of a time where participants were working towards a common goal as defined by themselves. A group of boys within a workshop decided that they would have a competition to see who could make the tallest tower (See figure 38).

> *'One of them started talking about how a triangle is the strongest shape to build a tower from. One boy used a triangle for the base and drew up from the three points. Another boy decided to make lots of triangle outlines. He told me that he planned on attaching the triangles to each other and making a tall structure that way. By the end of the session two of the boys had made towers that were really tall. The one made from individual triangles was very impressive looking but was not very high as he had made a more spread out composition. The other one had lots of supports drawn from the paper up to the top of the tower. He was really happy and described in detail how he had*

managed to get the tower to stand up by adding the supports.' (Appendix 3: diary entry 146)

This behaviour occurred in a workshop which took place at a youth club. As shown in the example there is often competitiveness amongst the young people. However, in the case of using a tool new to them, a 3D printing pen, the boys showed more interest in how they constructed their towers and overcame problems such as balance, than in who won the competition. This suggests that by providing young people in a youth club with a common goal and providing them with tools to make something, they may become more engaged in learning how to make their object well, rather than fastest, highest or any other dimension which could be viewed competitively.

5.3.1.1 'Soft' theory

When children use tools such as 3D printing pens in informal maker education environments, they will likely engage in problem solving behaviour. This can instil positive attitudes towards failure within children. Additionally, they are likely to engage in learning processes which require problem solving when the learning material relates to existing interests. Maker environments help children to develop a scale of risk tolerance which helps them to know how much risk is reasonable or appropriate. However, when children are engaged in the making process within a large, chaotic group such as in a busy youth club, it can be beneficial to give them a common goal as they will likely try to help each other overcome problems as they work through their projects.

5.3.2 Social learning

Out of 148 workshops analysed, 56 showed evidence that children were observed engaging in social learning during the 3D printing workshop. This shows that in 37.8% of 3D printing workshops children were engaged in social learning. It can be seen that in workshops which took place in a school setting (type C) engagement with social learning took place in 51.8% of the workshops compared to just 29.6% in type A workshops, 42.5% in type B workshops and 33.3% in type D workshops.

In stage 1 of this research the type of workshop which showed fewest instances of social learning were Type A workshops with less than one third being recorded as having social learning behaviours take place. However, despite this figure which may be explained by participants happily working by themselves on their own self-directed project, there was one instance in particular which showed the benefits of maker learning for engaging children in social learning. The example below relates directly to the example given in the problem solving (type A) example above in section 5.3.2.

> *'The boy who has been working on Iron Man for months finally finished. It is huge and so heavy! He did it in his own drawing style which makes it even more special…The other boys were impressed by the scale of the Iron Man and said they couldn't believe he finished it after all that time…Some boys said they were going to start something today and, in a few months, it would be just as big.' (Appendix 3: diary entry 66)*

When participants were able to see the result of another child's hard work and perseverance which they had witnessed over several months, it provided these children with an opportunity to see what was possible with commitment and hard work. This boy inspired his peers to also commit to working on a long-term project. It is easy to get disheartened when working on something for a long time when it is not clear when the work will be complete. However, this boy gave these children an appetite for commitment, trust and patience to engage in long term making. This example shows that maker education provides children with opportunities, not just in terms of material and tool options but also with regards to the attitudes and behaviours they can witness and learn from peers who have embraced a maker mindset which teaches them the value of commitment, trust, patience, perseverance and hard work. This echoes Vygotsky's theory of the 'more knowledgeable other' where children learn to reach their capacity when shown what and how others who have achieved that capacity already (see chapter 1).

Just less than half of type B workshops were recorded as having shown children engaging in social learning behaviour. Most of the participants in Type B workshops were friends already and as such this may account for these types of workshop being conducive to social learning. The participants felt comfortable with each other and therefore were less reserved about asking questions or discussing their creations. The example below describes one of the quieter participants who rarely spoke and spent most of her time focused on her own projects rather than socialising. The researcher-facilitator was making a flat 3D printing pen drawing of a tiger stand up by adding a small base perpendicular to the drawing.

> *'I added a stand so that the relatively flat drawing could stand up. Initially the girl tried to just copy what she could remember me doing but when she could not get it as neat as mine, she asked me to show her how to make a stand.' (Appendix 3: diary entry 24)*

This example shows that making can be used with shy or quiet children who are reluctant to verbally engage with their peers or adults, to provide a motivation for talking. The girl wanted to make a stand in the same way she had watched the researcher-facilitator do it but could not get the result she wanted and so she asked for help. By providing children with motivation to talk to their peers and adults, children can feel more comfortable talking in front of others and benefit from improved confidence, which might make asking for help less daunting in other scenarios.

Just over one third of type C workshops observed in stage 1 of this research showed evidence of social learning behaviours. These workshops were delivered in a classroom and as such children would be in the habit of asking questions. However, the opportunity or confidence required to learn directly from peers is less likely due to the more competitive environment of a private school (Anand et al., 2009). Therefore, this figure is consistent with what one would expect regarding social learning in a classroom setting. The example provided below shows evidence of a child learning by interacting with a 3D printer and observing and then imitating it, much like the girl in the previous example.

> *"One boy was staring at the 3D printer and watching the layers build up on the toy soldier that was being printed. He then took his pen and tried to replicate exactly what the printer was doing. I said that he was making a great job of it and he told me he finally understood how the printer worked." (Appendix 3: diary entry 109)*

The above example shows that a child was able to confidently say that they understood a new concept once they had spent time watching and experimenting with the technique. 3D printing pens afford participants the opportunity to try out new ideas and by having a 3D printer in the classroom they were able to relate the two tools to each other to better understand the process of layering plastic to create depth in a model. Maker tools integrated into education environments provide children with the opportunity to play and explore new ideas and concepts in a controlled, real life setting.

Type D workshops observed in stage 1 of this research were the least conducive to social learning. These workshops took place in youth clubs which tend to be places that children and young people go to play and socialise with friends. It is therefore unsurprising that children and young people were not observed to be learning from their peers or by asking questions as much as the other types of workshops. However, social learning opportunities can occur in unexpected ways. The example below describes a boy whose significant learning outcome was not when using the 3D printing pen as it was expected to be used.

> *"One of the boys was getting really frustrated and I couldn't seem to get him to believe me that he was doing well. One of the pens had jammed earlier so I gave him a screwdriver and asked him to open the pen up. Once he had it open, I showed him how to unjam it. He was delighted with himself that he had fixed it. He spent the rest of the night asking if there were any pens that he could fix." (Appendix 3: diary entry 139)*

This example shows the importance of being able to adapt to each participant when facilitating a workshop. The boy described was very disheartened and exhibited low self-esteem and confidence. He did not believe that he could make something he was happy with. Despite many attempts to encourage and praise the boy, the researcher-facilitator was not able to encourage the boy to try for long enough to see evidence of his own capacity. In this case, the researcher-facilitator felt that it was important to show him that he could do something well before he gave up and left the activity and so she provided him with a screwdriver to fix the tool that he felt unable to use. This example demonstrates the role that a facilitator can play in facilitating the learning and in this case empowerment of a participant. Being flexible with the learning outcome of the activity meant that the boy was able to have a positive experience, feel good, and learn about the inner electronics of a 3D printing pen, knowledge which he can apply to other electronic goods.

5.3.2.1 'Soft' theory

Social learning can be considered an expected outcome of engaging in maker workshops in informal education. Maker environments provide opportunities for children to learn from the successes of their peers; provide a motivation and safe place to develop confidence to ask for help; offer opportunities to explore new concepts in a physical, but controlled space in which they can develop their understanding; and, finally they are flexible environments. Children can try different approaches to making things and even different approaches to interacting with the tools which can lead to spontaneous and meaningful learning.

5.3.3 Proud of achievement

Out of 148 workshops analysed, 62 showed evidence of being proud of achievement. This shows that in 41.8% of 3D printing workshops children felt proud of themselves. It can be seen that in workshops attended by an unrelated group of children (type A) expression of pride in achievement took place in 39% of workshops compared to 30% in type B workshops, 16% in type C workshops and 16% in type D workshops.

A little more than one third of type A workshops observed in stage 1 of this research showed evidence of participants feeling proud of what they had achieved. Pride in achievement is self-recognition of something well done and was evident alongside increased confidence indicated by chattiness in these workshops. The example provided below includes the characteristic desire to show the researcher-facilitator what they had done which was common to most instances of this behaviour.

> *'The boy who told me the pile of plastic next to him was his first 13 mistakes last week excitedly told me that he finished the foot of his Iron Man and showed me a block of red plastic. He was so pleased, and the other boys were excited for him to and told him that it looked really good and sturdy. This led to a conversation about the qualities of Iron Man.' (Appendix 3: diary entry 25)*

This example shows that when children are given the opportunity to work on self-directed projects, they will feel happy and accomplished when they reach milestones, such as finishing 'the foot'. When a child openly expresses pride in their work, it provides the opportunity for a peer discussion which can give a child more confidence and can create a friendly, social space to discuss common interests and ideas.

Type B workshops showed few recorded instances of pride in achievement, which was observed at just less than one third of all workshops. This may be related to the fact that most participants were amongst friends where an atmosphere of "banter" existed. However, there were instances where participants were overcome with delight in their own achievement. The example provided below shows the value that children place on being able to do things by themselves, even if they do not want to in the first instance.

> *"Once he had finished this first model, he wanted me to do the outline again. I said that I was sure that he could do it. He refused and I said that if he tried thirty times and still couldn't make it work then I would help him. He agreed. After about seven tries he shouted, "I did it!' He looked so happy with himself." (Appendix 3: diary entry 101)*

This example shows that children value and appreciate that which they are fully responsible for more than something they only contribute to. Additionally, by placing a limit on how many attempts a child should make, it gives them motivation to keep trying. If the researcher-facilitator had told the child to keep trying, the indefinite number of attempts expected may have made the task seem unappealing or even impossible.

Type C workshop observations were joint lowest for the occurrence of pride in achievement. This may be influenced by the expectations of a child in private education. Children in private education are often expected to be high achievers and therefore may be more self-critical and less likely to express pride in achievement (Carey, 2014: 25). However, there were several instances where participants were happy with what they had created. In line with the example above, a boy also experienced delight when he was solely responsible for something he had made.

> *'One boy who desperately wanted my help, but I said only after fifteen attempts to said he couldn't believe he had managed to make the bauble for the Christmas tree. He held it against his chest and said, "I made this all by myself."' (Appendix3 : diary entry 85)*

This example shows that the value that children place on things that they are fully responsible for is also significant in young children who are using the 3D printing pens in a school setting. Additionally, by putting an upper limit on number of expected attempts children are likely to keep trying.

The joint lowest recorded observation of pride in achievement was in Type D workshops. However, there were instances where children did express pride. The example provided below describes a girl whose grandmother was in hospital and she wanted to make her a fully 3D printed card using the 3D printing pen.

> *"The girl finally finished her card and it looked amazing. Everyone commented on how lovely it was and said her Gran would be so pleased. She smiled a huge smile and said "I really worked hard on this. I don't think I've ever tried so hard at anything before. I love this!"" (Appendix 3: diary entry 146)*

This example shows that when children determine their own outcome, they work hard to achieve it. In this instance the girl acknowledged that making the card was the most hardworking she had ever been. She was motivated to make the card for her sick Gran and as such she was determined to complete it which gave her drive to do the job well and to completion. Perhaps if making was widely introduced into formal education, children would benefit from being able to choose their own projects for their own reasons, which may help them to stay focussed and engaged in doing the work well.

5.3.3.1 'Soft' Theory

Children who engage in making often express pride in what they managed to achieve. This can be argued to increase confidence and provide opportunities for self-reflection which helps children to identify times where their hard work paid off. Additionally, the data relating to pride highlighted the value that children place on things that they managed to make entirely by themselves. Making provides the opportunity for this to happen often.

5.3.4 Opportunity to communicate with peers about themselves

Out of 148 workshops analysed, 76 of them were recorded to have included children communicating with their peers about themselves. This shows that in 51.3% of 3D printing workshops children spoke about themselves. From the data, it was shown that 44.7% of workshops attended by a group of unrelated children (type A) showed that they took the opportunity to communicate with peers about themselves whereas this was recorded on 34.2% in a weekly club setting (type B), 11.8% in a school setting (type C) and just 9.2% in a youth club setting (type D).

Type A workshops were observed to be the most conducive to participants taking the opportunity to communicate with peers about themselves. Conversations about personal interests occurred before and after engaging in the making process and so it could be argued that it is the maker environment which provides children with the opportunity, comfort and security necessary to talk about themselves to peers. The example provided below describes a scenario where a group of boys were talking about a common interest, Pokémon, which lead to one of them creating something inspired by their conversation.

> *"Three of the other boys were making Pokémon figurines. They chatted about which Pokémon they had caught that week. This led to a very excited conversation about the different Pokémon. One of the boys showed me the app and showed me which Pokémon he had collected. I commented on how cool it would be if they actually had shelves in real life showing all the Pokémon they had collected. The boy said, "oh yeah!" before running back to his desk and making a mini shelving unit and adding miniature versions of all the Pokémon characters that he had caught on to it." (Appendix 3: diary entry 116)*

This example shows that when the researcher-facilitator joined in on a conversation that the boys were having, she was able to identify what one of the participants was excited by and make suggestions for an object which he would be able to make using the 3D printing pen. This suggests that where making is integrated into formal education, it would be beneficial for the facilitator to allow children to talk about themselves and their interests so that children can find ideas and projects that will delight them. A facilitator should also try to engage with participants so that they can understand what drives them and be in a position to make suggestions. This may enable learning to take place through ideas or projects which excite the child.

Just more than one third of all type B workshop observations showed that participants took the opportunity to talk to peers about themselves. The example provided below shows that participants may use the making process as an opportunity to talk to others about something they are excited about but may feel less inclined to share it without the prompt of their creation.

> *'I asked him what he was going to make, and he said he was making his football team's badge. He was recently chosen for a football team which is quite prestigious. After he started making it, I asked him about when he got picked and what it's like playing with them and he chatted about that more than I've ever heard him talk before…When the rest of the boys arrived…they were talking to the younger boy about his new football team.' (Appendix 3: diary entry 65)*

This suggests that children who are generally quiet or shy in social situations may feel more confident in sharing their stories when they have a reason for doing so. In the scenario above, a boy made the badge of his new football team using a 3D printing pen. This prompted the researcher-facilitator to ask about it and gave the child the chance to talk about their hobby in front of the whole group which led to further discussions among the participants. This shows that environments where making can occur may provide people with a chance to share their own stories which can be particularly useful for people who are less inclined to talk to others about themselves.

Very few type C workshops recorded participants taking the opportunity to talk about themselves to their peers. However, similar to above, in the few cases that children did talk about themselves they spoke to the researcher-facilitator and she suggested that they could make something related to their story with the 3D printing pen.

> *'One of the girls was excited to tell me that she had joined a Rainbows group. She told me all about her first night there. I suggested that she could make a rainbow with the 3D printing pen. She loved this idea and went over to the filaments to collect the colours that she needed.' (Appendix3: diary entry 115)*

This example occurred within the classroom of a private school and therefore talking amongst the children usually relates directly to the task as it would during school hours. However, as can be seen in the above example children often come to tell the researcher-facilitator things that have seen or done over the previous week. By listening to these stories, the researcher-facilitator is in a position to make suggestions to the participants which will give them further opportunity to engage with their peers about their personal stories. This suggests that when making, it may be beneficial to break away from traditional classroom rules about talking and provide children with the opportunity to talk to their peers about themselves by allowing unrelated discussions or in cases where children are reluctant to do so, make suggestions for project ideas which will make participants feel more confident in talking about their personal stories when they can discuss it through their made artefact.

Instances of participants taking the opportunity to talk about themselves to peers were rare in observations of type D workshops. However, in sessions where there was a small number of participants it did happen. The example below describes the role that being engaged in the making process often provided participants with a prompt to talk about a personal interest.

> *"Some other boys came through and sat quietly making some game pieces for their games. They were really quiet, apart from one boy who talked a lot about the board game they were playing. At the end they all gathered everything they had made including the initial messy ones and took them home with them" (Appendix 3: diary entry 136)*

This example echoes the findings of type B and type C examples. A participant confidently spoke to the group about a board game after he had begun making pieces for this game. The artefact which he was engaged in making gave him a way to talk about his interest without talking about it directly.

5.3.4.1 'Soft' theory

It can be reasonably assumed that informal maker learning environments provide a space where children can feel comfortable in talking to others about themselves. The data shows that the process of making or a self-made artefact can act as a conversation prompt, which motivates children to talk to others about themselves. Additionally, it can be beneficial for facilitators to engage with the children's conversation so that they are better positioned to guide children in their learning through ideas which excite them.

5.3.5 Experience of agency

Out of 148 workshops analysed, data from 59 of them showed evidence that children had experienced agency. This shows that in 40.6% of type A workshop children experienced agency compared to 30.5% in a weekly club setting (type B), 16.9% in a school setting (type C) and 11.8% in a youth club setting (type D).

Type A workshop observations have the highest instance of children experience agency which may be impacted by the fact that children who go to these weekly clubs attend with the intention of learning to make things using 3D printing technologies and therefore, are perhaps more likely to experience the empowerment afforded by tools of digital fabrication. The example below describes a time where a girl was able to defy her mother's rule of not getting a fidget spinner by making one for herself.

> *"The girl in the group doesn't have her own spinner yet, she said her Mum will not allow her to get one. She was so excited that she could make one. She carefully chose the colours and concentrated really hard as she made all the lines melt neatly together. She finished it and came running up to me to show me and demonstrate the fidget spinner spinning. I told her that I was so impressed, and she gave me the biggest smile before running back to make her friend one." (Appendix 3: diary entry 100)*

The above example shows that despite the questionable ethical aspects surrounding defying parental authority, by having access to tools of digital fabrication participants are able to create objects which work similarly to something they would otherwise have to buy. When children witness their own power, they may begin to see themselves as productive individuals who can make an impact on their immediate environment, social or physical, even if just in a small way to begin with.

Type B workshops observations showed than in just less than one third of type B workshops participants experience their own agency. Experiencing agency was observed through many behaviours as described in Chapter 4. However, the most common behaviour which gave children an experience of agency was making something for someone else. The example below describes a workshop at which a group of boys were making a get well soon gift for one of the boys who regularly attends who was in hospital.

> *'The boys who did come said they wanted to make a present for the injured boy. One of the boys spent time on the laptop make a house using Google SketchUp. The others made a 'card' for the boy. First, they made a frame which two of them worked on. Then someone else made a hatched pattern across the frame. Another one did some 3D lettering.' (Appendix 3: diary entry 63)*

This shows that when children are not constrained by predetermined project plans they have the opportunity to create something which they are committed to and willing to work with others so that they may accomplish it, particularly when the making process is time limited due to external factors: in this case one of the boys was visiting the other boy in hospital that evening and so the gift had to be completed by the end of the 3D printing workshop. This example proposes the importance of free-making opportunities to allow participants to learn to balance their ideas, desires, expectations, abilities and time to produce something which satisfies each constraint.

Less than one quarter of observed Type C workshops showed that children experienced agency. However, there was one particular instance described below, which shows the potential for extent of agency possible through making.

> *'One of the girls was really excited when I came in. She came up to me and told me that she was a big sister. I said that was amazing and asked about her new sibling. She told me that he had been born the day before, but she hadn't met him yet. She said she wanted to make a present for him. She drew a blue love heart and asked me to help her write "I love you [his name]" inside the love heart. I helped her and then we used a piece of ribbon I had in my bag to tie a bow on it so it could be hung up. She thanked me for helping her and had the biggest smile on her face. At the end of the class her Mum came in carrying her brand-new baby brother. She looked so happy and quickly ran to her bag and took out the heart she had made for him and held it out in front of him. It was such a beautiful moment.' (Appendix 3: diary entry 119)*

This example shows how important the ability and opportunity to make, is for children. Welcoming a new baby into the home can be a difficult time for young children as they learn their new role and consider their place within the family. This girl wanted to perform her role as 'big sister' by giving the baby a gift. This may generally by done by having the child choose something in a shop which the parent then buys for the child to give to the new baby. However, in this instance the girl was able to take full ownership of this process and create a gift that she not only chose but designed and made by herself. Making affords children the capacity to create 'real' things and therefore give gifts which would never be possible without parental assistance. The power of this could be significant in the way they view themselves.

There were few observations which showed that children experienced agency in type D workshops. However, several participants used the 3D printing workshops as an opportunity to make something for someone else. The example below shows where making differs from other art forms available to children.

> *'One girl made a little memorial thing to take to her Dad's grave. She made it heart shaped and then added her Dad's name and drew a trophy on it which said Hibs.' (Appendix 3: diary entry 135)*

This example highlights the significance of the physical material when creating things and how alternative materials which are available in maker environments can facilitate actions which would otherwise be less successful. The girl in this example wanted to make her Dad, who had died, a picture. Making pictures for parents is common among children of all ages. However, leaving a picture made by traditional means (paper, paint, pencil etc.) at a graveside will likely result in the picture being ruined which could be distressing to a child to find the next time they visit. The girl in the example was able to make 'a picture' for her Dad with the 3D printing pens which use ABS plastic which can withstand extreme weather conditions making it an appropriate medium for creating pictures which need to be left outside. This example shows that making can provide a solution to problems faced by children who are already experiencing hardship.

5.3.5.1 'Soft' Theory

Having access to tools which enables them to make things, gives children power and allows them to experience their own agency. Making 'real' things allows children to have and witness their own power in a tangible way. It also gives children practice in balancing constraining factors of an activity which help them to learn how to navigate these constraints such as time, personal expectation and personal ability. Additionally, the vast range of materials available in general maker environments mean that children are not restricted to one type of making which may have been the case in that past.

5.3.6 Satisfaction with outcome

Out of 148 workshops analysed, 54 of them were recorded as having evidence that children were happy with the outcome. This shows that in 36.4% of 3D printing workshops children were pleased with the workshop. The data shows that 38.8% of type A workshops noted that children were happy with the outcome compared to 33.3% in a weekly club setting (type B), 12.9% of workshops which took place in a school (type C) and 14.8% in a youth club setting (type D).

The data relating to this category is less indicative of how making impacts the behaviour of children and more generally about children's response to having the opportunity to make and how they feel about it. Therefore, this category will not be analysed in the same way as the previous category and will instead be used as an indication of whether children were happy with their creations at the end of a workshop.

5.4 Phase 7: Verification research

This section will outline the approach taken in conducting verification research, how the sample was chosen and what conclusions may be drawn from these results.

5.4.1 How the verification research was carried out

The verification research was designed around the findings of stage 1 of this study. As can be seen in the previous section (5.3) there were six defined categories representing the most commonly observed behaviours in 3D printing workshops. These were: problem solving, social learning, expression of pride in achievement, opportunity to communicate with peers about themselves, experience of agency and satisfaction with outcome. As discussed, these categories were defined following observations documented in diary entries. A diary entry is limited in the amount of detail it can capture. Therefore, it was deemed advisable to conduct verification research to determine the true number of workshops in which each defined behaviour occurred. It was expected that the number of workshops exhibiting these behaviours would be higher than what was initially recorded.

The research was conducted using a tally-checklist as defined in Chapter 3. A sample tally-checklist used in stage 2 of this research can be found in appendix 6. The tally-checklist has been populated with the six categories discussed in the previous section and beside each category there is space to write ‘yes’ or ‘no’ to note whether the behaviour was observed and in the next column shows the percentage of participants who exhibited this behaviour across the 10 verification workshops.

5.4.2 Sample of verification research

The workshops used for this verification research were chosen as they were the next workshops to be conducted as part of the researcher’s personal work. In order to get an even sample of each type of workshop and enough data to provide a consensus, it was decided that the next ten workshops of each type, for which consent could be acquired, would be the sample for verification. These workshops took place between July 2019 and September 2019.

5.4.3 Verification research results

The following table displays the results of the verification research.

Category	A		B		C		D	
	Occurrence (Yes/No)	% of Participants	Occurrence (Yes/No)	% of Participants	Occurrence (Yes/No)	% of Participants	Occurrence (Yes/No)	No. of children
Problem solving	Yes	96 %	Yes	64%	Yes	100%	Yes	80%
Social Learning	Yes	77%	Yes	42%	Yes	92%	Yes	15%
Proud of achievement	Yes	77%	Yes	43%	Yes	48%	Yes	23%
Opportunity to communicate with peers about themselves	Yes	94%	Yes	93%	Yes	68%	Yes	14%
Experience of agency	Yes	61%	Yes	39%	Yes	48%	Yes	38%
Satisfaction with outcome	Yes	100%	Yes	99%	Yes	100%	Yes	99%

Table 24 Frequency of observed behaviour in verification phase of research

5.5 Statistical analysis of data and theories across types

This section explains the significance of findings across different types of workshops by statistically analysing the results of the verification research.

Four types of workshop were taken forward for analysis and these were type A, B, C, and D, (see Chapter 4 for outline of each type) while six categories regarding observed behaviours were defined in section 5.3 of this chapter. It was considered worthwhile to statistically analyse these to ascertain whether the differences observed between workshop types were due to chance. This may be valuable to further explore issues of experience and accessibility to digital making for leisure and its associated benefits. Furthermore, understanding the occurrence of behaviour associated with the different environments and social settings of these workshops may uncover opportunities to improve the integration and uptake of these tools in formal learning environments.

The method for statistical analysis used was unpaired 2 tailed Student's t-test[16]. This was deemed the appropriate statistical test as the data was made up of group types which were not dependent on each other and had little variability as the confirmation research involved 40 workshops in total, 10 of each type. . This section will show which results are statistically significant and therefore indicate that the differences observed are not due to chance. The verification workshops had a total of 515 attendees.

SPSS version 24 was used for statistical analysis. For the purposes of this study, each workshop was entered as a different case. The six behaviour categories were the variables associated with values of the percentage of participants exhibiting the different behaviours. A further dummy variable was coded to allow the workshops to be grouped by type (A-D) and therefore to allow comparisons between these groups.

The null hypothesis for this analysis was set as 'there was no expected difference between workshop types' because the same tools and information was available to all participants so it may be expected that any participants in any group would exhibit similar behaviours. Therefore, any significant results indicate a difference between the workshop type. These differences suggest that the workshop environment or demographic of attendees for the different types of workshop may be affecting the exhibited behaviours and therefore their experience with digital making. There may be many alternative contributing factors, but this is outwith the scope of this thesis.

[16] Unpaired 2 tailed Student's t-test is a simple statistical procedure which can compare two independent groups compared against different variables.(Horne, 1998)

	Problem Solving	Social Learning	Proud of Achievement	Opportunity Communicate with Peers	Experience of Agency	Satisfaction with Outcome
Type A-B	3.047 ($p<0.05$)	2.724 ($p<0.05$)	2.668 ($p<0.05$)	0.631 (not sig)	1.759 ($p<0.1$)	1.00 (not sig)
Type A-C	-1.00 (not sig)	-1.394 (not sig)	2.548 ($p<0.05$)	3.547 ($p<0.05$)	1.302 (not sig)	N/A[17]
Type A-D	1.347 (not sig)	4.686 ($p<0.05$)	4.684 ($p<0.05$)	6.902 ($p<0.05$)	2.809 ($p<0.05$)	1.00 (not sig)
Type B-C	-3.492 ($p<0.05$)	-5.246 ($p<0.05$)	-0.383 (not sig)	2.483 ($p<0.05$)	-0.731 (not sig)	-1.00 (not sig)
Type B-D	-1.847 ($p<0.1$)	2.163 ($p<0.05$)	1.493 (not sig)	5.661 ($p<0.05$)	0.297 (not sig)	-1.00 (not sig)
Type C-D	1.951 ($p<0.1$)	7.933 ($p<0.05$)	2.126 ($p<0.05$)	3.345 ($p<0.05$)	1.543 (not sig)	1.00 (not sig)

Table 25: Statistical analysis showing t-value for unpaired, independent sample, 2-tailed t-test, $p<0.05$ is deemed significant.

The t-values for the difference between workshop types are presented in Table 25. The p-value in brackets indicates the level of significance. For the purpose of this thesis a p value <0.05 is considered significant and indicative of marked differences in behaviours exhibited by participants of different types of workshops. At this level of significance, the null hypothesis will be rejected. This value represents the 95% confidence interval[18]. Where the p-value is <0.1, this has also been included to highlight where there are notable, but not significant differences between the groups. This shows that there may be a difference between the groups, but the evidence is not sufficient to reject the null hypothesis.

Problem solving

[17] Standard deviation of occurrence of this behavior for Workshops A and C is equal and therefore it is not possible to obtain value for t-test

[18] 95% confidence interval demonstrates that if further samples were taken and the confidence interval was calculated, 95% of these intervals would contain the population mean (Smithson, 2003),

Using the data collected, problem solving was shown to occur significantly more in type A workshops than type B to a 95% confidence interval and more in type C than type B to a 95% confidence interval. These were the only two workshop comparisons that showed a significant difference. (See table 4, Category 1, Chapter Analysis for description of behaviours.) Type B to Type D and Type C to Type D groups show a difference at the 90% confidence interval, suggesting there may be a difference between these two workshops, but this is not significant enough to reject the null hypothesis.

This suggests that Type A workshops are more likely to involve problem solving behaviour than Type B. This echoes the earlier interpretation that participants attending a class by themselves with the intention to learn and make with 3D printing technologies are more likely to engage in the learning process which involves problem solving. Whereas Type B workshops were attended by a group of friends who, perhaps attended to learn as a secondary motivation to attending to socialise with their friends. Type C workshops also show a higher likelihood of engaging participants in problem solving behaviour which can be explained by the fact that these workshops take place within a classroom in the school of all of the participants. There are no other significant differences between groups regarding problem solving behaviour which suggests that Type B workshops are the least conducive to problem solving behaviour which may be a result of participants attending as a social engagement rather than workshop, class or activity.

Social learning

The data collected shows that social learning behaviours were exhibited significantly more in type A than type B workshops; type A than type D; type C than type B; type B than type D and type C than type D workshops. The only workshop types where there was not a significant difference in the exhibition of social learning behaviours was the type A-C comparison.

This suggests that Type A workshops are more likely to involve social learning than Type B workshops. This may be because the motivation for attending Type A workshops is to learn and make using 3D printing technologies. However, Type B workshops in the data were attended by a group of friends interested in learning and making using 3D printing technologies. This shows that perhaps the social aspect of Type B workshops may be the greater motivation and it could just be one or two participants who are very interested in 3D printing and the rest attended to be with their friends. Type A workshops were also more likely to involve social learning behaviours over Type D. For the same reasons as described above, Type A workshops are conducive to social learning due to their motivation for attending. However, from the data in table 20 it can be seen that social learning does occur in Type D workshops, but less often. This suggests that different motivations and expectations can greatly influence the likelihood of social learning occurring. Type C workshops are also more likely to have social learning take place than Type B or Type D workshops. This is likely explained by the setting of the workshop, Type C workshops take place within a school which the participants attend and therefore they are more likely to be in mindset to learn and treat the workshop as a school lesson. There is no significant difference between the social learning which occurs in a Type A or Type C workshop, concurrent with the interpretation above, it can be assumed that these types of workshops are places where participants have the greatest desire and expectation to engage in learning.

Expression of pride in achievement

The collected data shows that the expression of pride in achievement occurred more in type A than type C workshops; more in type A workshops than type D and more in type C than type D. There was no significant difference between type B and type C or type B and type D workshops.

This suggests that Type A workshops compared with Type C and D are more likely to result in participants feeling pride in their creations. The difference between Type A and Type C could be explained by the environments in which the workshops take place. A six-year-old attending private school may have higher expectations of their ability than a child attending a 3D printing club and therefore may be less likely to exhibit behaviours associated with pride.[19] The difference between Type A and Type D workshops may be explained by the relationships between participants. Type

[19] Children who are expected to be high achievers are reported to be less likely to be happy with their work (Carey, 2014).

A workshops are generally attended by participants who want to learn to make things using 3D printing technologies and so the participants are working towards a common goal. However, at Type D workshops, participants are more likely to be concerned with how they are coming across to their peers rather than acting on their personal desires.[20] This explanation may also be echoed in the reason for the difference between likelihood of pride in achievement between Type C and Type D workshops, where children using 3D printing technologies in a private school environment may be more assured that they can express pleasure in their own attainment.

Experience of agency

This analysis shows that using the data collected, type A workshops exhibit experience of agency behaviours significantly more than type D workshops.
This is the only significant difference between workshops exhibiting behaviours associated with experiencing agency. There is difference between A-B workshops at the 90% confidence interval, but as discussed this is not deemed sufficient to reject the null hypothesis.

Considering this, it can be deduced that a type A workshop is more likely to be conducive to producing problem solving behaviours than type D workshops. From the descriptions of workshop types (See table 9) the cause of this difference may be explained by the environment in which the participants are working. The participants in Type D workshops are generally new to using 3D printing technologies. The motivation for Type D participants attending a 3D printing session within their youth club is often secondary to being fed and spending time with friends. Whereas participants attending a Type A workshop are motivated to attend because they want to use the technologies. This may suggest that participants are more likely to experience agency when using 3D printing technologies when they are using the technology with intention of making something and not because it is merely something to do while socialising with friends.

[20] Social and economic status are shown to have significant impact on acceptance in community youth clubs and as such young people often feel insecure regarding where they belong within the group. (Marshall, 1958: 174)

Opportunity to communicate with peers about themselves

The data collected shows that, taking the opportunity to communicate with peers about themselves occurred significantly more in type A workshops than type C; more in type A workshops than type D; more in type B than type C; more in type B than type D; and more in type C than type D. In this case the only comparison in which there was not a significant difference was the type A-B comparison.

This suggests that Type D workshops are the least conducive to participants talking about themselves to each other. This may be because it is an environment for people of all interests and backgrounds to come together and so participants may feel less inclined to share personal information or interests with the group. Type C workshops are the second least conducive to this type of behaviour. This may be because these workshops take place in a school setting and although they occur after school time, the participants are still complying with the rules, behaviours and structures of their classroom. Additionally, these children come from different families and have different interests so again, perhaps this is why the participants feel less inclined to discuss their interests and lives with each other. Type A and Type B workshops have no significant difference in participants exhibiting this behaviour. The similarity between these groups regarding their motivation for attending may be a contributing factor to why participants of both these types of workshops are inclined to talk about themselves and their personal interests. They may believe that they are among like-minded people where the other two group types are more mixed.

Satisfaction with outcome

The data collected shows that every participant was happy with what they produced at the end of the workshop. Therefore, there is no statistical difference between workshop types and as such it can be assumed that all participants of all group types described will finish the workshop with something that they are happy with. No significant difference between these groups was found.

5.5.1 Statistical analysis conclusions

The statistical analysis of behaviours exhibited in different types of group has shown that despite the appearance of how the groups are attended and engaged in, the behaviour may be driven more by the motivation of participants who take part.

Type A workshops were shown to be the most common workshop types for significantly higher rates of exhibited behaviour. This may be due to the fact that the participants chose to attend week by week in order to learn how to use 3D printing technologies. The participants become comfortable with the content and expectations of the workshops. Further, there was no expectation of these participants to attend. They were never expected to be there and therefore had the freedom to choose whether or not to engage. This means that the main motivation for doing so was to use the 3D printing technology so they are more likely to exhibit all of the isolated behaviours: problem solving so they could continue with their self-directed project; social learning positioning the experience as a learning process; experience agency as they had the freedom to choose what to make and therefore experienced greater power when they did create something; talk about themselves to their peers if they knew they were amongst like-minded children and therefore felt less self-conscious regarding how and what they spoke about; and finally they were happy with what they made.

Type B workshops were expected to have similar results to Type A due to the setting of the club and age range of participants. However, it was shown that this type of workshop was less conducive than Type A for the facilitation of learning based behaviours (problem solving and social learning) which may be explained by their motive for attending. If the participants were attending because their group of friends were, it would only need one or two children interested in learning about 3D printing for the whole group to attend and as such the learning opportunities were not taken to the same extent as Type A workshops. As attendance at this group was motivated by social interaction, this workshop type was conducive to social based behaviours (talking to peers about themselves and expression of pride).

The data from analysis of Type C workshops show that the learning-based behaviours (problem solving and social learning) were commonly expressed in these types of workshops. Learning-based behaviours were expected due to these workshops taking place in a school classroom. The social-based behaviours (talking to peers about themselves and expressing pride in their achievement) occurred less often, perhaps due to compliance with school rules and structures relating to behaviour and conduct or because the group of children were attending largely for the convenience of childcare than the desire to learn a particular skill.

The data from analysis of Type D workshops were the least conducive to all isolated behaviours. The motivation for attending Type D workshops was not usually to engage in a 3D printing workshop. Type D workshops were run within existing groups and therefore participants were attending their regular club and on particular nights 3D printing was an optional activity. Therefore, despite the children and young people enjoying and being excited to try 3D printing they did not attend with a particular prior interest or intention to learn or make anything. As such, the motivation to overcome problems or learn from conversation with the facilitator or others was less pressing. Additionally, due to the mix of people attending the young people may have felt self-conscious about how they came across to their peers therefore engaging in personal conversation or expressing pride in achievement was less prevalent in these types of workshops.

5.6 Conclusion

This chapter explained how six final categories were taken forward for further research in this study. These were then analysed with regards to the observation diary entries and 'soft theories' were derived from this information.
A short summary of these soft theories are:

1. Children with access to maker tools engage in problem solving which instils positive attitudes toward failure. This provides more conducive environments for deep learning, to understand risk and become engaged in learning to make things well.
2. Informal maker learning environments provide a space where children can learn from the success of their peers, the motivation to ask for help, the chance to develop deep understanding through exploration of concepts in the physical world and flexibility for children to learn from a plurality of approaches.
3. Children value being able to do something entirely by themselves and making provides the opportunity to make something 'real' with little or no

assistance from adults, this leads to recognition of their own hard work and in turn increases confidence.

4. Making provides children with a physical prompt which they can speak about and relate to their own personal stories about their own lives which they may desire to share with those around them.
5. A self-made artefact allows children to witness their own power in a tangible way and understand their place within the immediate environment.
6. Making gives children the potential for power and multiple applications for their endeavours, they are not constrained by material restrictions as is typical within traditional children's art making.

This chapter then detailed the verification research which was carried out to check for the behaviours or defined categories discussed in section 5.3. An additional 40 workshops were delivered and the results of these were analysed using the unpaired 2 tailed Student's t-test. The statistical analysis showed that the motivation for engaging in informal 3D printing education has a significant impact on how successful the learning that takes place is. The isolated behaviours are more likely to take place in a workshop which children freely attend with the intention to learn and make using 3D printing technology and feel comfortable surrounded by like-minded peers. The analysis also showed that the isolated behaviours can be split into two areas, social-based behaviours and learning-based behaviours. Type A is conducive to both areas of behaviour. Type B is conducive to social based behaviours. Type C is conducive to learning-based behaviours. Whilst all behaviours were observed in Type D workshops, behaviour categories defined in this thesis were observed less frequently than in the other workshop types.

The next chapter will review existing research before considering the findings of this study within the context of broader maker research.

Chapter 6

6.1 Overview

This chapter will provide a review of literature relevant to the findings discussed in the previous chapter. Its purpose is to provide context for the theories generated from this research. The developed theories were grounded within the data itself and took a constructivist approach to understanding the meaning of the data. The scientific method was then applied through statistical analysis of the verification study. The chapter will present existing knowledge and research under five sub-headings. These are: ‘Art, craft and making’, ‘The Maker Movement’, ‘Making and learning’, ‘21st Century skills’ and ‘Power, empowerment and autonomy’.

6.2 Art, craft and making

6.2.1 Art

E.H. Gombrich (1994) said, ‘There really is no such thing as Art.’ (1994:21) The word has been overused and misdefined for generations so that to describe something as art does not mean much. It merely describes a product of creative activity, which is intended to be appreciated in some way by the observer. Therefore, it is the observer who can define something as art. There are the visual arts, which include painting and sculpture. There is also conceptual art, which promotes an idea or concept that the artist has. There are performing arts where the artists use their bodies and movement to express themselves such as dance or mime. The types of art are numerous, and many overlaps exist. This illustrates Gombrich’s sentiment that art does not exist in and of itself as most activities could be described as art if someone was to define them as such. He goes onto say, ‘There are only artists.’ (1994:21). This study considers art as something created with the intention of being art. It takes a human-centric approach where objects are considered as a creative output of a human and value the intention and experience of creation rather than focussing on the object that is created.

Art therapy is a growing field of practice and research (O’Connor & Shaefer, 1994). The process of making art is increasingly becoming recognised as having a positive impact on an individual's physical, mental and emotional well-being (Titus & Sinacore, 2013). Studies (American Art Therapy Association, 2009; Canadian Art Therapy Association, 2012) show that the process of making art and the product that is made, 'helped individuals cope with emotions, thoughts and bodily symptoms; fostered a positive self-image; and enhanced social relationships, thus promoting a sense of well-being.' (2009; 2012:29). These studies focus on people who suffer from a health condition. However, the outcome can positively be applied to individuals in different contexts. Reynolds (1997) observed that making art holds the attention of individuals so that they can temporarily escape from negative thoughts and emotions. More studies by Reynolds (2004; 2010) explain how making art holds an individual's attention. He says that the aesthetics of making art, including the colours, smells and textures, help to immerse an individual and evoke a sense of pleasure and energy while connecting with life outside of the art making experience. The studies of Reynolds (Ibid) also explain that when an individual makes art, it is a physical reminder to them and people around them that they are capable and valuable individuals who are not defined by anything that may be afflicting them. The art pieces themselves provide evidence of learning and skills development which document the overcoming of difficulties, which leads to satisfaction and a sense of achievement (Titus & Sinacore, 2013 after Reynolds, 2010).

Art making also allows individuals to feel that uniqueness is a positive attribute which allows them to know that it is alright to be different to others (Howie et al., 2004). This can be a liberating realisation as it helps to free people from the pressures of conformity and helps to build their self-esteem and self-confidence. Additionally, self-esteem can also be helped with art making as it provides a space for positive feedback and recognition (Titus & Sinacore, 2013). Furthermore, making art in the presence of others provides access to networks of people who will share ideas, skills, techniques and will offer support (Ibid, 2013). These opportunities are valuable and can lead to advice and support that extends beyond the art making process to include the discussion of services available socially and financially, which have the potential to make a difference to an individual's life.

When regularly engaged in art making, particularly if it is physical work outside of a contained sketchbook, there will be a surplus of artworks which amateur artists will often give as gifts or donate to fundraisers (Ibid, 2013). This sharing of art and generosity that comes alongside this, allows individuals to feel that they have contributed something or have been kind. This helps to change the perception others have of them or that they have of themselves (Reynolds, 1997).

Art therapy for those who do not identify as having a health condition was explored by Titus and Sinacore (2013). They conducted a study they hoped would fill a gap that they identified in the literature that, 'given that young adulthood is associated with many changes and stressors (Arnett, 1998), some of which may be specific to women, art-making may serve as a means to maintain and enhance women's well-being during young adulthood.' Their study looked at young women artists who self-identified as healthy to understand their art making practice in relation to the context in which art making happens and what influence it has on a young woman's well-being. The study found that in particular, context art-making fostered well-being in healthy young women and as such suggested that therapists find out from their patients if they already make art and if so focus on the context in which they do this in order to improve the potential of engaging in the activity of making art. Performing arts have also been shown to have a positive impact on the social skills development of individuals. Kenrick's et al. (in Karkou et al., 2017: 568) study showed that girls engaged in community-based dance classes were able to attain a high standard in their dance practice as well as experience an improved social integration. This further supports the notion that location-based art practice can maintain or enhance the well-being of young women.

Further research

This discussion of the emotional benefits of engaging in the practice of making art shows that there is potential to using art with both healthy and unwell people. It can increase their sense of well-being, self-esteem and confidence by immersing them in the activity using colour, smells and textures. However, most of the literature that discusses art making does not convey whether the participants were already inclined to make art. Therefore, it cannot be said with certainty that those who have no interest in art or making art will also enjoy the benefits that participants in the discussed studies have. Additionally, the studies largely focus on young women by citing research that suggests that some changes and stressors in young adulthood are specific to women. However, this argument could be developed further to explore the differences in the changes and stressors affecting young women and young men, with a strong argument for doing research specific to all genders.

6.2.2 Craft

Craft is a skilled activity in making things by hand (Adamson, 2013), that humans have participated in for thousands of years (Parnell & Terry, 2002). However, craft has only been defined as it is understood today since the mid-19th century when Britain and America were beginning to experiment with machines for production (Frayling, 2011). There was a fear that the craftsmen would be made obsolete and craft was romanticised by theorists of the time (Ruskin, 1863; Morris, 1884). Before then craft was an essential skill for making practical things. As populations increased and demand grew capitalist economies took advantage of advancing technologies to meet demand. Frayling (2011) argues that the contemporary narrative of what craftsmanship was in the 19th century is mere nostalgia.

> ‘The myth of the happy artisan- like the ‘artist craftsman’, ‘craft guilds to which select potters could belong, and the confusion of rural workers with guild craftsman- did not exist until the nineteenth century, when it became part of a romantic reaction against the spread of industrial capitalism. And the history which underpins much of the ‘craft revival’ is, in fact, nostalgia masquerading as history.’ (2011:66)

This narrative is not isolated to contemporary interpretations. Morris (1884) discusses ‘useful work’. He argues that work done by hand is more valuable than work done by a machine both in terms of the article itself and in the benefits it brings to the craftsman and society (Morris, 1884). Despite this 19th century anxiety that machine would replace man

> ‘most current research into this history seems to be proving that hand-work and mass-production industries existed side by side into the late 19th century, and that the specifically English experience of industrialisation involved a close interaction between the two.’ (Frayling, 2011 :79).

Although theorists and contemporary writers romanticise what craftmanship was before the industrial revolution, current research does agree that the participation in craft is beneficial to well-being. Sennett (2009) says that, ‘Craftsmanship names an enduring, basic human impulse, the desire to do a job well for its own sake.' (2009:4). This sentiment is further illustrated by Kenning (2015) whose research into craft and well-being shows that,

> 'craft-based textile activities encourage mental and physical engagement, stimulation and challenges, social interaction, and meaningful solitary activities that contribute to healthy ageing.' (2015:62).

The growing recognition of the benefits associated with participating in craft-based activities is contributing to the cyclic revivals of craft. Since the industrial revolution there have been many periods of renewed interest in craft. Most notably these have been in the 1920s agricultural depression, post-war Britain; and, most recently after the economic crash of 2008 (Bratich & Brush, 2011). It can be argued that this is due to less disposable income being available which leads to people attempting to make or mend what they need. Alternatively, it may be down to an industrial fatigue which causes a longing for a simpler time where more control could be had over one's own life.

6.2.3 Craft and its place alongside art

Adamson (2007) says that 'craft's position within the arts is a complicated affair.' (2007:2). He argues that craft should not be considered as art because this is too simplistic and deprives craft of having a theoretical framework of its own. He says that craft is a process and that it 'only exists in motion.' (2007:7). This elevated perspective of craft is unique within literature. Dormer (1997) says that, 'craft skill is considered to repress creativity and is regarded as an easily acquired service for self-expression.' (1997:103). Craft is often considered as less important than art. (Adamson, 2007).

6.2.4 Making

In the context of this research, 'making' refers to the activity of creating things motivated by the experience of the process as much as by the end product. This type of creating has been collected under 'The Maker Movement' which can be considered as an extension of the DIY sub-culture to include technological advancements (Hatch, 2014). 'The Maker Movement' was defined as such in 2005 with the launch of *Make* magazine by Dale Dougherty and later by Maker Faires which have become regular international celebrations of making. (Dougherty in

Thomas, 2014) 'The Maker Movement' will be discussed in more detail in section 6.3.

Maker values, which Thomas (2014) defines as; 'curiosity', 'playfulness', 'risk-taking', 'responsibility', 'persistence', 'resourcefulness', 'generosity' and 'optimism' could be developed in young people to make them feel empowered through the process of making. The technological advancements referenced above include 3D printers, CNC machines and laser cutters. These are machines which allow anyone with the inclination to make something, which looks professionally manufactured.

As with art and craft above, making can arguably facilitate wellbeing and have an empowering effect on the makers. Rusk (in Peppler et al., 2016) says that, 'people inherently enjoy making things' (2016: 87). Making is perhaps the activity which most closely relates to Morris' reference to 'useful work', which makes people feel productive and experience the associated positive feelings of achieving something. Space10 (2017) argue that making allows those who do not have the opportunity to make, create or do anything practical in their jobs, make hobbies out of activities that could be considered as work just so they can feel the satisfaction that comes from doing something practical well.

Judkins (2014) discusses the ability of making to facilitate thinking. He says, 'If you want to formulate new ideas, think with your hands. Make something as you reflect.' He also discusses the feeling of empowerment that making develops. Lipson and Kurman (2013) talk about making as a means of expression. Manufacturing tools are now more accessible to the non-professional allowing people to express themselves through the new creative technologies. They say that this is 'empowering through mastery of the means of expression.' (2013: 253). This further illustrates the capacity of making to lead to a feeling of fulfilment in the maker.

6.2.5 Art, craft and making together

The activities of art, craft and making are described in their distinct categories above. The motivations for taking part and how the completed artefact is viewed, treated and shared were discussed. Additionally, each section concluded with an exploration of the therapeutic capacity of each activity. Art has a growing academic tradition of being used as a therapy. Craft is recognised as something which people engage in to feel fulfilled and to possibly save money or be more eco-minded (Frayling, 2011). Making has less of a reputation or tradition for facilitating well-being. It is regarded by those who do discuss it to be akin to craft in terms of the social and economic benefits (Sinikka, 2015).

Though discussed as distinct activities, the three are often referred to as being the same in educational literature (Beaven, 2011). Crawford (2009) uses the word art to explain how children develop their own ideas and critical thought. Despite his use of the word art, he is referring to creative outputs which are not restricted to the definition of art. He goes on to say, 'Without the opportunity to learn through the hands, the world remains abstract, and distant, and the passions for learning will not be engaged' (2009:11). This further illustrates how academic literature often reduces these activities to one pursuit. For the purposes of this thesis, the distinction between art, craft and making in literature are defined in the 'Definition of Key Terms' before the introduction to this thesis.

6.2.6 The Maker Movement

Overview

The Maker Movement emerged in 2005 and came as a response to the advances and mass adoption of computer technologies (Hatch, 2014: 3). It has its foundations within the DIY sub-culture of the 1970s and 1980s while incorporating the technologies now available to people of all backgrounds, professions and interests (Gershenfeld, 2007). In the last 15 years 'The Maker Movement' has gained popularity and interest across society. Entrepreneurs have used the affordability of tools available to develop low cost prototypes (Gebhardt, 2016). Businesses have engaged with it to provide their employees with design thinking training (Smith & Mader, 2017). Hobbyists and craftspeople have taken advantage of the tool options and accessibility and increased number of makerspaces (Anderson, 2013). Finally, schools have been incorporating maker education into their traditional woodwork classes as well as science, technology, engineering and math (STEM) education (Irwin et al., 2014). As a worldwide phenomenon, 'The Maker Movement' has become the subject of research as academics and interested parties want to find out more about what drives people to want to make things for themselves and what benefits this is associated with. This section will detail the following, how making relates to the self, the connections that making facilitates, making and children, and making and learning.

6.2.7 How making relates to the self

As described above, making has the capacity to make an individual feel fulfilled.

> 'Making is fundamental to what it means to be human. We must make, create, and express ourselves to feel whole. There is something unique about making physical things. Things we make are like little pieces of us and seem to embody portions of our soul.' (Hatch, 2014: 11)

Creating physical things can be seen as a type of liberation. Marx (1947) spoke about the power that belongs to those who have control of the means of production. When one can create something from one's own mind and capacity, they can experience personal and intellectual fulfilment as well as potential to be economically autonomous (Anderson, 2013).

In addition to being able to make something with one's own capacity, making can enable people to witness and therefore believe in their own capacity. Leadbeater (2009) argues that in a society where everyone has access to hundreds of sources of information people begin to rely on the advice, opinions, services and information that others put forward and value their own capacity less. He advocates that, 'people should spend less time as consumers, more as producers' (2009: 44). Despite this call to action, it could be argued that one would have to be in a position of power already to recognise the potential for or see worth in becoming empowered. Making as a leisure activity takes effort and resources and as such it would be necessary for people to feel motivated to begin the activity.

Motivation to make has been discussed at length by theorists to explain why people intentionally take part in something which in other contexts would be considered as work (Morris, 1884; Ruskin, 1863; Crawford, 2009; Frayling, 2011; Dewey & Ratner, 1939; Hatch, 2014). They agree that the capacity to make things is a human resource and that by engaging in it, people become occupied by a feeling of fulfilment and completeness. Described in a more tangible way, by being able to engage this human resource one can become more productive in all areas of their lives as they become connected to the physical and emotional worlds around them.

Self-determination is a theory which indicates that when people feel autonomy, relatedness and competence they are more likely to experience an improved sense of well-being and therefore want to express themselves and make their own decisions in their own directions (Ryan & Deci, 2000). Despite the seemingly personal attributes of these experiences 'The Maker Movement' attributes much of its appeal to the subjective experience of social transactions which occur in maker environments. Therefore, social engagement may be considered as a motivator for engaging socially isolated people in maker environments which has been successfully achieved through initiatives such as Men Sheds (see below) (Gauntlett, 2016: 113; Macaskill, 2018).

6.2.8 Making facilitates connections

The Maker Movement is based on communities of people who get together to make or share their ideas, creations and skills with each other. Initiatives such as Men Sheds expand physical locations where people can access makerspaces, provide a place where people can go to be surrounded by a diverse group of people who share ideas, values and interests (Mark, 2018). Gauntlett (2016) said that groups who get together to focus on a particular interest are likely to meet a wide range of people who will, 'challenge narrow perceptions and prejudices.' (2016:159). However, as a result of the computer revolution and the mass adoption of the internet, communities of makers do not have to live in the same country or even speak the same language to be able to interact with each other (Allan et al., 2018). This provides people with the opportunity to be part of a wider community where they can interact with others and make friends across the world. People who have experienced social isolation have explained the impact that online maker communities have had on their well-being and sense of connectedness. A study by Rusk (in Peppler at al., 2016) about participation in Scratch[21] communities describe a young person who said that they

[21] An online coding platform where people, particularly children and young people, create projects and share their ideas and knowledge.

would not be here today if it were not for all their great friends on Scratch. They explain that people on Scratch like and care about them (Rusk in Peppler et al., 2016: 95). This highlights the support and important relationships which can exist in online maker communities.

There has long been a recognition of the benefits of gathering in communities to work towards a common goal or skill acquisition (Baden-Powell, 2015; Magyarody, 2016). The scouting movement began as way for boys to contribute to the expansion of the British empire (Baden-Powell, 2015). It was believed that by being of service to their communities the boys could cultivate the skills, character and discipline necessary to become strong men fit to uphold the empire, in the anxious political climate of post-Boer war Britain (Boehmer, 2004, in Baden-Powell, 2015: xix). The movement was adopted across Britain and influenced the creation of a girl's order, The Girl Guides (WAGGGS, 2019). Despite much criticism throughout the history of these youth organisations (Boehmer, 2004, in Baden-Powell, 2015: xix), they are widely believed to have a positive impact on young people and the development of their character, practical and employability skills (Scouts, 2019). The Boy Scout and Girl Guiding movements encourage participants to collect badges which are awarded for participation and skills acquisition in particular activities. These include many maker-based activities (Ibid, 2019). Children can pursue their badges independently or as part of a group, which provides them with motivation and support while working towards their goals. This shows that there are organisations which provided networks of potential maker communities a hundred years before the emergence of 'The Maker Movement'. Therefore, this supports the notion that participation in groups can lead to improved well-being and skills development.

There was a suggestion by critics that online communities could not offer the same level of interaction or well-being to people due to the digital divide and the risk of people becoming uncritical consumers of information (Zittrain, 2009). However, there is now far greater access to the Internet due to public Wi-Fi and internet enabled devices which will increasingly reduce the digital divide (West, 2015). Furthermore, the increased use of platforms for content creation such as YouTube indicate that there are a significant number of producers dedicated to producing good and unbiased content (Olsson, 2019).

Connecting with other people on a regular basis is recognised as having a positive impact on both individuals and wider society (Putnam, 2000; Bourdieu, 1989). This impact can be described by the framework of social capital. Social capital is a way of thinking about the value, impact and importance of social relationships in society (Putnam, 2000). Capital is referred to as an economic resource (Conway, 2009). Putnam (1993) defines social capital as a ‘public good comprised of trust among a diverse group of citizens’ (1993: 103).

Trust between members of a community contributes to lower crime rates and generally happier citizens who feel safe (Lederman et al., 2002). Links between low social capital and unemployment, drug and alcohol problems and crime rate can be made globally (Åslund & Nilsson, 2013; Berkman & Kawachi, 2000). Larance (2001) highlights that where social capital is high, citizens tend to be trustful and cooperative. Alternatively, in a less fortunate regions which lack social capital, citizens can be distrustful and uncooperative. Salaj and Putnam (2004) further illustrate this correlation, explaining that where citizens are members of social groups there is higher social capital.

Putnam (2000) provides a comparative analysis between Britain and the USA regarding social capital associated with membership of social groups. The term ‘membership’ is used loosely, to describe regular attendance at a formal or informal social group or event (Ibid). Associating with others in a public space is credited with increasing social capital (Ibid; Larance, 2001; Putnam, 1993).

Despite the seemingly overwhelmingly positive results of increased social capital there are many criticisms of enthusiasms for social capital as a solution to problems. These enthusiasms are notably advocated by Robert Putnam. Putnam (2000) conveys a belief that if people come together to engage in a shared activity people will be happier and society will be better. However, he observed that reliance on social cohesion as a solution to societal ills could be seen as absolving the government of responsibility and reducing services which limit social unrest. Additionally, to assume that people coming together in groups is always positive is perhaps naïve and also ignores the potential tribalism (Putnam, 1993) that can result from groups loyal to a particular cause. However, Putnam (2000) suggests that engaging in community activity is more beneficial than being isolated and alone. Social capital can therefore be considered as positive in theory but applications of it should be considered in terms of lived experience and not assumed to be inherently positive.

Collaborations are key to 'The Maker Movement' as people seek comfort from those who share their passion and advice and guidance from those with a different skillset to their own. Make magazine, a publication aimed at hobbyists and tinkerers, created an early readership community in 2005 before the first maker faire in 2006. The maker faire has grown into a series of annual events with an attendance of 200,000 people worldwide (Make, 2019). These events provide a platform for makers to engage new audiences and create networks with other makers. The apolitical nature, widespread adoption and plurality of opinions and ideas could be argued to protect makerspaces and maker communities from the negative aspects of social capital.

6.2.9 Making and children

So far, this literature review has largely dealt with making as an activity and pursuit of adults. However, making is something which children do every day, through their play (Montessori, 1959). When children are given access to tools of digital fabrication it can be enlightening to discover what they make (Gershendfeld, 2007). Children introduced to making tools, and more specifically, digital fabrication tools, can consider uses for tools that adults would struggle to conceive as children are not restricted by preconceived notions of manufacturing. Gershenfeld (Ibid:65) explains that watching children play with maker tools reminds him that it is important for everyone to have the opportunity to make and not just those who are privileged enough to have access to institutions which typically house makerspaces. When children are given tools with which they can create their own ideas they grow up, 'thinking of engineering as something that they can do for themselves' (Ibid). In addition to the empowerment that they may experience through the affordance of professional tools, making can be argued to help children develop critical thinking.

Leadbeater (2009) argues that it is art which provides children with the opportunity to ask questions, challenge ideas and develop their own thoughts and ideas. When a child has created something, they experience agency and competence as they see the effects of their own work and witness the recognition in those around them. Art and making provides a type of social currency. Hung et al. (2019) discuss the use of making to teach children to thinking critically. Their study is based on maker projects, where one group of children must define a problem (problem guiding) and then work towards a solution. The other group is provided with a problem (problem solving). It was found that the problem guiding lesson was preferable for providing deep learning opportunities but due to time constraints and potential teacher bias, problem solving lessons would be easier to implement with a predetermined set of learning objectives (2019: 61). This suggests that making can be used as a way to develop children's' critical voices but is vulnerable to teacher interference due to time and budget constraints in the classroom.

Making provides opportunities for children to not only develop their skills and understanding of the digital tools they use but also to:

> 'explore their agency and self-efficacy…the broader benefits of maker-centred learning are more characterological in nature- they are dispositions, ways of being, and ways of seeing the world.' (Oxman et al., in Peppler et al., 2016: 42)

This shows that children engaged in maker practices can conceive of uses for maker technologies that could otherwise be unrealised, and can develop critical thought. For these reasons they can witness their own efficacy and understand that they can make change and have impact in the world.

Eisenberg (2013) drew similarities between where computing was in the late 1970s and where 3D printers are now (2013: 7). He says that it seems quaint to imagine that people believed that computers were not suitable for children, and advocates that the same mistake should not be made with 3D printers (Ibid: 8). However, he does say that improvements should be made to make 3D printers more accessible for children. He makes many suggestions regarding how he imagines this could happen. One suggestion is there could be a portable 3D printing device, or a tool designed for hand-customisation (Ibid: 8). Nemorin and Selwyn (2017) describe the provision of a 3D printing pen to allow students to customise their car designs. This could be argued to be the type of solution which Eisenberg (2013) was looking for. In the example provided by Nemorin (2016) she explains that some students used the pen while waiting for their models to print but most did not use the pen as a means of decorating their models beyond adding their names. She said that participants were more concerned with how their model would function. This positions 3D printing pens as an additional tool which was not engaged with with the same seriousness as the 3D printer. [22]

6.2.10 Making and learning

The previous section discussed the suitability of making for children with regards to it being something they do naturally and without a predetermined set of rules that no longer apply because of advances in digital fabrication. It has been argued that making offers an opportunity for children to experience agency and self-efficacy. Therefore, it is appropriate to consider the role that making has and could play within educational contexts.

When a child is making something, they must consider how they want it to look and work before acquiring the knowledge, skills and understanding necessary to achieve their goal. Therefore, 'making brings about a natural interest in learning' (Hatch, 2014: 20). Leadbeater (2009) suggests that it is important for children to have the opportunity to play and make with their hands so that they have a tangible understanding of the world around them.

The integration of making into formal education has become popular and a subject of interest among many educators and researchers who recognise the benefits of making for children (Resnick et al., in Peppler et al.,2016: 234; Van der Poel et al., 2016; Chu et al., 2015). Lipson and Kurman (2013:154) explain that, 'children learn through experimentation much more than by recitation and repetition.'. There is a consensus that making provides an opportunity to reignite the 'learning by doing' educational theory as proposed by Harel and Papert (1991) and Piaget (in Boden, 1988, 3rd ed.). However, Resnick et al. (2016) warns that making is at risk of being used simply as a method for passing on knowledge to children. Making can provide more beyond knowledge transmission. It has the potential to give children the skills

[22] See Chapter 7 for a full discussion on how this compares to the findings of this research.

and confidence to pursue their own passions and become lifelong learners and creators.

One way making builds confidence is by teaching children how to overcome failure. Failure is something which everyone must learn to recover from (Balk, 1983) and it is perhaps one of the most character-building traits of an engagement with making (Oxman et al,. in Peppler et al., 2016: 35). Bjork & Bjork (2011) discuss notions of desirable difficulty and Warshauer (2015) explains that struggling can be productive. Lipson and Kurman (2012) describe 3D printers as a way to

> 'help high school design and engineering students fail more quickly…the faster you fail, the more quickly you arrive at a solution.' (2012: 158)

Making provides constant opportunities for failure but the negative response associated with failing is reduced when it is possible to press 'undo' in the software (Ibid, 2012). As in the example shared by Nemorin (2016) the solution to her problem was clear immediately as she had not made a space large enough to accommodate the battery pack. However, Nemorin (2016) challenges the valorisation of failure in the literature on making as she feels that the immediate lived experience can be frustrating and disheartening. It should therefore be considered that despite the experience of failure being seen as necessary and beneficial from afar, it is important not to expose children and young people to unnecessary failure to avoid disillusionment or disempowerment. Maltese et al. (2018) suggest that teachers must support children and young people through the challenges (2018: 117) by normalising failure, minimising contributing constraints such as time, not solving the problem for them and suggesting that they ask peers for help or use resources found online (2018: 123).

In a review of research on 'The Maker Movement' with regards to learning, Papavlasopoulou et al. (2016) say that the interest in integrating making into education are focused in STEM education. This review shows that maker activities result in an increased self-efficacy among participants which improves confidence and enjoyment, fostering a particular interest in the subject being studied. This study also describes a lack of negative responses to making in education, which they argue is good but means that there is a lack of understanding on how to prevent negative experiences in future (Ibid, 2016). There is however evidence of negative responses to making in education in the qualitative studies of Nemorin (2016), Nemorin and Selwyn (2017) and Song (2018). These studies describe problems in uptake of 3D printing due to inadequate resources or teacher knowledge.

Nemorin and Selwyn (2017) describe a 3D printing class project where a teacher purchased a 3D printer with little practical knowledge of how they work but with an enthusiasm to deliver a design project for his class. Nemorin participated in the class project and noted that despite the excitement and engagement that 3D printers initially offer, they were slow and unreliable meaning that student excitement waned. [23]

Concerns that the failure of education to quickly communicate technical developments stagnates the adoption of the technology were raised by Ford and Minshall (2019) in their extensive review of all uses of 3D printers in education. They argue that teachers play a significant role in the impression that 3D printers have on their students and that there was a lack of appropriate support for teachers to communicate this effectively. They also highlighted a significant lack of published studies based in primary school aged groups.

Chu et al. (2015) agree with Papavlasopoulou et al. (2016) and say that most reported cases and research of making in education discusses making as a means of transmitting knowledge about STEM based subjects. They, however, argue that making should be seen,

> 'as a means to inculcate a 'Maker's mindset' that has a far greater impact than the teaching of any specific subject matter at the elementary grade levels.' (2015: 11)

Considering the studies of Flores and Springer (2013), Posch and Fitzpatrick (2012) and Alexander et al. (2018), it seems that much research discusses the value of the 'maker mindset' defined as a growth mindset facilitated by making which believes that capabilities can be developed, improved, expanded and risk and failure can be tolerated (Dougherty, in Honey& Kanter, 2013: 9). However, Chu et al. (2015) explains that research which expresses the benefits of a maker mindset do not

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[23] Refer to chapter 7 for further discussion regarding this.

present empirical evidence and that most initiatives provide only informal or anecdotal evidence of the effectiveness of their approach. They argue that because of a lack of empirical evidence the value of making as a means to an end in and of itself is not being recognised.

Song's study (2018) argues that there is insufficient training for teachers available regarding the integration of 3D printers into learning environments. She uses the Technological, Pedagogical and Content Knowledge (TPACK) framework (see figure 1) devised by Shulman (1986) to explain how the triangulation of understanding of pedagogy, content and technology is necessary to successfully use the digital tools to support the teaching of pre-defined content. Song (2018) advocates the use of alternative learner-centred teaching approaches including project-based learning (PBL) and using flipped classrooms [24] but is critical of the, 'adoption of new technologies without development of suitable pedagogies related to specific features of those technologies' (2018: 195). This study appears to treat maker-based education as a way to carry out learner-centred teaching rather than recognising the importance of the developed behaviours associated with making. However, it does add to the growing advice that a standardised method of integrating making into the classroom is necessary to ensure its consistent success.

[24] Flipped classrooms is an approach to teaching which gives responsibility for learning the necessary material to the students and class time is used for inquiry or project-based learning. Teachers provide recorded lectures for the student which they are expected to watch in advance of the class. When they come to class they should already be equipped with an understanding of the lesson, knowledge which they can use to explore and experiment with, in class (Bergmann & Sams, 2012:6). Using this method provides children with the time they require to learn the material and it is estimated that it works for 80% of students compared to traditional teaching which works for just 20% of students (Bergmann & Sams, 2012: 51).

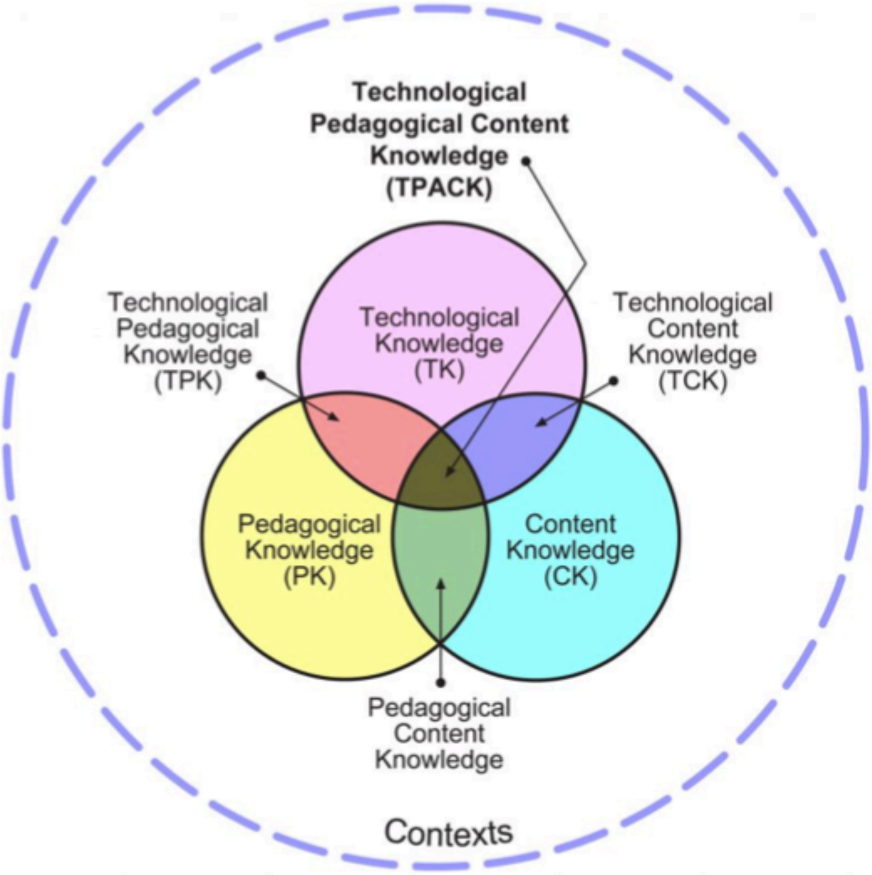

Figure 1 TPACK framework (Shulman, 1986)

6.3 3D Printing pens

This section will discuss all known academic literature which refers to 3D printing pens to provide an overview of how 3D printing pens are used and thought about in different contexts and for different applications.

3D printing pens are hand-held tools which allow the user to operate the extrusion of plastic through a shaft and control where the material is deposited. A typical 3D printing pen looks like the diagram shown in Figure 2.

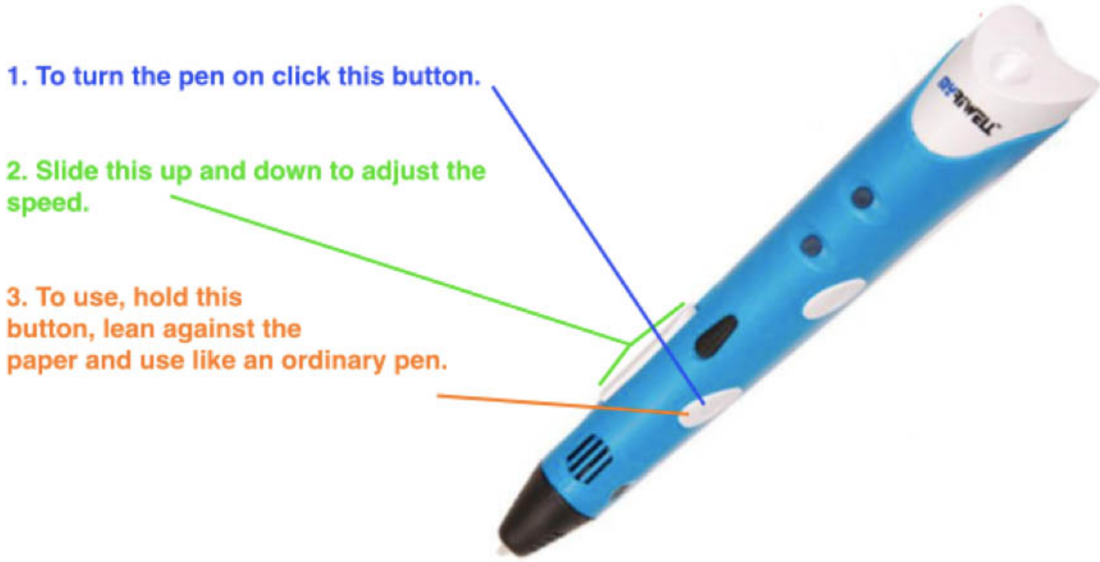

Figure 2 3D printing pen diagram (Allan, 2016)

The materials which are commonly used in a 3D printing pen are acrylonitrile butadiene styrene (ABS) and Polylactic acid (PLA). Strands of the plastics are fed into the top of the pen and using the 'on' button shown by the blue and orange lines in Figure 2. The plastic is extruded through the hot-end, at temperatures of between 190 and 230 degrees Celsius. The pen can be held and moved as one would write with a conventional pen. The plastic can be extruded onto paper and used as a 3D ink or it can be drawn up from the paper and into the air to create wireframe, three-dimensional drawings (Gogoi & Jeyapoovan, 2016). (See Figures 30-35).

3D printing pens are sold as a children's toy through companies such as Amazon (Amazon, 2019) but are also marketed as a tool for artists and designers (Ibid, 2019) though there is little evidence of them being used for this purpose within research. Where 3D printing pens have been discussed within research, the uses for them have been varied.

Dean et al. (2016) describe a study where they used 3D printing pens to give first year university students the opportunity to conceptualise valence shell electron pair repulsion (VSPER) theory in three-dimensional space. VSPER theory is an essential concept for organic and inorganic chemists to understand (Ibid, 2016). Traditional methods for teaching this concept include using polystyrene balls and pipe cleaners.

However, Dean et al. (2016) argue that by using 3D printing pens students can learn in a more meaningful and hands on way. Additionally, because the material is inexpensive students can take their models home with them and may show them to others which can result in other learning and teaching opportunities which otherwise would not occur (2016: 1662).

Hancock (2015) describes the use of 3D printers and 3D scanners in museums to deepen engagement between young audiences and museum collections. She describes the use of 3D printing pens at an exhibition at the British Museum in 2014. She explained that 'to compliment this activity, children were able to design their own amulets, brought to life using 3Doodler pens[25], which create 3D shapes from plastic filament as you draw' (2015: 34). The use of the phrase, 'to compliment' suggests that 3D printing pens are additional to 3D printers and not a significant tool in and of themselves.

Gogoi and Jeyapoovan (2016) explain in detail how a 3D printing pen works and describes the capable and functional objects that it can create. They advocate 3D printing pens as a low-cost alternative to 3D printers. Additionally, they provide schematics showing how a 3D printing pen can be attached to a frame and controlled using Arduino[26] so that it can be used as a functional 3D-printer (2016: 756-760).

Finally, the only other research that can be found which discusses 3D printing pens are papers written or contributed to by the author of this thesis. These are, Allan[27] (2018a, 2018b, 2018c), Vettese et al. (2017) and Vones et al. (2018). These discuss the use of 3D printing pens to engage patients in their medical decisions (Allan, 2018a); re-engage disengaged young people back into education by facilitating a relationship with older people (2018b); convey the possible benefits of engagement with digital fabrication (2018c); facilitate engagement with maker-culture across generations (Vettese et al., 2017); and engaged children with concepts of re-manufacturing by giving them the opportunity to make using plastic from the ocean (Vones et al., 2018).

[25] A 3Doodler is a commercial brand of a 3D printing pen.
[26] Arduino is an open source electronic prototyping platform.
[27] The author of this thesis, Denise Milne, was formerly called Denise Allan.

The research available which was not conducted or contributed to by the author suggests that 3D printing pens are not being treated as a serious tool and are seen as something additional to 3D printers. However, there was one study which showed how 3D printing pens can facilitate the deeper understanding of complex chemical models (Dean et al., 2016). Additionally, Gogoi and Jeyapoovan (2016) describe 3D printing pens as a low-cost alternative to 3D printing pens.

Trust and Maloy (2017) describe a survey of teachers in the USA who use 3D printers in their classrooms. The study aimed to find out what their students made and what learning skills they demonstrated while doing so. The authors use the 21st century learning reports from The Advanced Harvard Leadership Initiative (2014), as well as Hanover Research (2011) and Wagner (2008) to provide a list of skills deemed necessary for the 21st century. These included teamwork, creativity, critical thinking, problem solving and adaptability. These skills were then considered alongside the results of the survey which showed that 61% of their learners engaged in teamwork, 90% engaged in creativity, 76% in critical thinking, 88% in problem solving and 57% in adaptability (2017: 264). Despite the affirmative nature of their data, Trust and Maloy (2017) caution that there is a steep learning curve required when using 3D printers and that failure is likely (2017: 255). Their study introduces the 21st century skills literature which argues that new skills must be integrated into the education system to prepare 21st century children for the future.

6.4 21st Century Skills

There is a consensus that the education system is failing to prepare students for work and that the system is no longer fit for the complex needs of society (Harvard Advanced Leadership Initiative, 2014). Reimer et al. (in Ibid: 2) discussed four main areas in which schools are failing. These were, a global and citizenship gap where young people are not aware of their role or responsibilities to the world on a larger scale; lack of system connectedness where each part of the education system operates in isolation of the others which leads to a disconnected system; standardized testing where students are examined on their knowledge using tests rather than considering their educational experience holistically; and, finally, their lack of means of evaluating teacher effectiveness (as the success of a teacher is not merely reflected by their student's grades).

Table 26 (below) shows skills which are defined as essential and desirable for success in the 21st century as described by the Harvard Advanced Leadership Initiative (2014).

Essential skills for success in the 21st century	Desirable skills for success in the 21st century
Critical thinking and problem solving	Entrepreneurial skills
Creativity and innovation	Financial literacy
Collaboration	Life skills
Question formulation	People skills
Global awareness	Self-direction
Communication skills	Personal and social responsibility
Technology skills	Character and citizenship

Table 26 21st Century essential and desirable skills

Table 26 describes essential skills alongside desirable skills for the 21st century learner. Despite there being variation in the labels given to these skills there is a consensus regarding the types of skills which are considered essential. Silber-Varod et al. (2019) describe the essential skills as: collaboration, communication, creativity, critical thinking, information literacy and socio emotional skills. They say that the mastery of digital technologies for social and emotional skills and digital literacies are seen as critical for educational settings (Ibid: 3100). A model conceived by the National Research Council (2012) defines 21st Century competencies as 'knowledge that can be applied or transferred to a new setting'. This illustrates the general notion of what 21st Century learners are required to be able to do.

Reichert and Mouza (2015) describe how iPads and mobile apps can allow for individualisation of the learning process, support 21st Century skills acquisition and enable learning to occur whenever and wherever is convenient. However, they describe the necessity of the educators in being able to support learners and ensure that these technologies are used appropriately to achieve their potential. Adamson and Darling-Hammond (in Griffin & Care, 2014: 301) say that there are not enough lesson plans and assessments available so that teachers may teach the necessary skills. To do so would require a significant investment of time and, due to the requirements of traditional testing, the opportunity to develop these lesson plans and assessments is not available. Additionally, they note that there are challenges in assessing the teaching of 21st Century skills (Ibid: 304). This shows that while 21st Century Skills are recognised as being important, there is a lack of support and infrastructure in place to allow these skills to be taught as standard.

Laar et al. (2017) describes the benefits of 21st Century digital skills as a catalyst for developing competitiveness and innovation capacity. They define seven key skills similar to those already stated but also offer five contextual 21st Century skills. These are: ethical awareness, cultural awareness, flexibility, self-direction and lifelong learning. These additional contextual skills provide a foundation on which to understand the 21st Century skills as composed of both creative and digital skills. Laar et al (2017) highlight that there is now a global knowledge society which means that people must have the relevant digital skills to actively participate in society. Also, due to changing demands of jobs it is essential that people can find and interpret information and develop ideas from it. Therefore, both digital and creative skills are seen as essential but not necessarily the same. Creative skills and digital competencies are essential to prepare children for the 21st century. Notably, digital skills are not solely sufficient for preparing children for the future jobs market, due to the speed of digital advances. These must be complemented by creative skills to develop flexibility to adapt to these advances.

Although there are many lists of 21st Century Skills deemed essential (Silber-Varod et al., 2019; Harvard Advanced Leadership Initiative, 2014; Laar et al., 2017), there are few frameworks used to conceptualise the application and interplay between these skills. The frameworks which do exist emphasise the following: the importance of socio-emotional skills to solve problems using software (Eshet-Alkalai, 2004); a triangulation between technical, cognitive and socio-emotional dimensions of digital literacy (Ng, 2012) and a more content-based skills development (Deursen & Van Dijk, 2010). Wee Replicators (2019), the company run by the author of this thesis, operates a creative digital literacy initiative. This is a framework used to illustrate the skills developed in each of the attended classes with there being an emphasis on the necessity to acquire both digital and creative skill types. This is to ensure that participants learn and develop a flexibility to adapt to any situation or technology they are confronted with. Many classes offered by Wee Replicators provide both types of skills to ensure that participants are learning to synthesise a combined response.

There are many ways to consider 21st Century Skills, however there is a consensus that developing these skills will help to prepare students and workers for a changing and unpredictable set of challenges through all areas of their lives.

6.5 Common theories of power

The feeling of fulfilment and empowerment provided to those participating in making is widely acknowledged (Charny, 2011: 7; Anderson, 2013:53; Thomas, 2014: 110). Therefore, it is important to understand power in this context to ascertain the implications of people gaining power through a maker practice. This section will explore common theories of power including normalisation, pastoral, truth and power potential.

Normalisation

Under the condition of domination normalisation 'becomes one of the great instruments of power' (Dore, 2010:743). State and government have a great deal of influence over what is deemed as normal, which is identified to suit their needs in order to maintain their power. An identification of what is 'normal' makes anyone who does not conform abnormal and as such they will face the social pressures that accompany non-conformity. Normalisation is an effective method to enforce the government's ideals throughout society. Normalisation shifts the directions of power so that it is self-policed at every level of the hierarchy to ensure conformity (Dore, 2010:743). Social deprivation and a lack of power feeds this system by creating an opportunity for people to take power from their peers by identifying where they are not conforming to what is 'normal'. Victimising non-conformity allows people to push themselves up the hierarchy and have more power. This is evident universally in both institutional settings as well as in both private and public space (Thornberg, 2013).

Pastoral

Pastoral power is another example of dominating power, which stems from state and government (Foucault,1976). The structure of society creates an expectation that people have a right to be healthy, to have a reasonable standard of living and to be safe (Equality and Human Rights Commission, 2018). These rights are met by roles such as doctors and the police. The people filling these roles are given an elevated status which leads to the assumption that what these people say and do is right, whereas there may normally be some critical reflection on things that are said and done by people without the elevated status and power (Foucault, 1976).

Truth

Nietzsche (1994; 1997) discusses the relationship between truth and power. He says that there are no absolute truths and that science cannot produce any more truth than a person in power. He argues that all information is held hostage by the limitations of language (Dore, 2010:745). People can interpret words differently and understand concepts and ideas from different viewpoints. Therefore, nothing can be absolutely true to everyone at any time.

This lack of absolutism leads to a paradox about which, Foucault (1976) says that 'We are subjected to the production of truth through power and we cannot exercise power except through the production of truth' (1976: 93). Considering this, information and knowledge become a complex network of subjectivity which is difficult to navigate. In order to comprehend the complexity, one must remain critical of all information and knowledge to ensure that they are not subsumed and maintain some power over themselves and their beliefs.

Potential power

Building on Russell's (1938) observation that power is to society what energy is to physics, there is another analogy from physics which fits with power in society, namely potential energy. It is defined as mechanical energy that is stored due to its position (Britannica, 2018). By analogy to power in society, it is possible to frame this as a metaphor for how a person may have the potential for power if they were to choose to exert it under the appropriate conditions. Someone who may not be described as powerful due to a lack of social status can still have the potential for power which they can exert or demonstrate if the conditions for 'being powerful' were not 'to have a high social status'. Taking this to the extent of Nietzsche's (1994) theory of truth it is possible to say that everyone has the potential for power but can only realise it when they are viewing it on the appropriate framework and not in that of society and state domination.

6.5.1 Empowerment as a modern paradigm

Empowerment is discussed widely in maker literature as well as social policy (Thomas, 2014; Gershenfeld, 2007; Zimmerman, 2000: 43). This section will consider 'power into empowerment', 'affirmation of personal capacity in contemporary research on power', 'knowledge' and 'participation and conscientization'.

Power into empowerment

In the previous section the concept and theories of power were briefly outlined to build a foundation for understanding how empowerment happens in contemporary society. Forms of power were discussed, which highlighted some ways that people can be in a position of being oppressed. When this occurs those, who form underrepresented groups may feel powerless and disenfranchised as their experiences, truths and needs are undervalued and dismissed (Coghlan & Brydon-Miller, 2014).

Affirmation of personal capacity in contemporary research on power

Contemporary research has suggested that there are three ways to consider power, these are: 'power with', 'power to' and 'power within' (Haugaard, 2012). These modalities are affirmative of people's own capacity to think and do something well. 'Power with' is the idea that there is strength in collectiveness, to find a common ground among a diverse group of people, and so to build support and solidarity. 'Power to' is the idea that everyone has the power to direct their own life and what they want to do with it. 'Power within' relates to a person's self-worth and learning to imagine and have hope. This central feeling of value affirms the human condition of desire for dignity and fulfilment (Jones, 2015). The last two forms of power can be described as agency, which is the ability to do something and make decisions for oneself (Emirbayer & Mische, 1998).

Knowledge

Knowledge is a way for one to recognise and conceptualise their ability and personal capacity which can contribute to a feeling of empowerment. Saks (2012) defines knowledge as an expertise. This can be a practical expertise, which allows one to physically do something. Alternatively, it can be a repository of information in the mind which allows them to apply that information appropriately to understand things. In contemporary society there is a prestige associated with the latter type of knowledge, while practical expertise seems less impressive (Elbaz, 2014; Arendt, 1998). This may stem from the value that is placed on things which are in print. Information can be conveyed through text with ease whereas a description of something which must be experienced to understand is not so easily translated into the written word.

Participation and conscientization

Coghlan and Brydon-Miller (2014) says that to embark upon an attempt at empowering disenfranchised groups, a researcher must take the time to learn and understand the existing power relations to find out where and how the people can take power. Participation in this unearthing of opportunities may be considered as being essential for one to become empowered. Friere (1996) talks about the 'conscientization' which involves allowing people to develop critical thinking so that they can take greater control and responsibility for the social and economic systems in their communities and societies. Once people develop the ability to think critically and develop their own ideas that they value, they will experience a capacity to make change. However, they must be given an opportunity to physically act on this and see their capacity for themselves (Coghlan & Brydon-Miller, 2014).

Once people feel empowered in one instance, they will be ready to take power in other situations. 'The success of one action sets in motion the flow of successive joint actions' (Coghlan & Brydon-Miller, 2014:3). Over time this will allow the newly empowered to organise their own power relations and structures, taking control of decision-making processes. However, in order for the improvements in agency to continue with every individual, people with power must take on the role of facilitator so they are not taking control of the empowerment of others.

‘Empowerment fosters capacities in individuals, groups and communities’. (Coghlan & Brydon-Miller, 2014:3). The process of empowerment must consider how the individuals feel and what they want and need. Empowerment involves a relationship of trust where individuals can become aware of their own abilities, clear on where they feel powerless and where they feel able to take power or at least the potential for power (Ibid). Empowerment does not happen quickly. It takes time to ensure that the transformation is permanent and in the best interest of the individual (Ibid).

6.5.2 Implications of autonomy

Empowerment is often presented as being an intrinsically positive goal (Travis, 2014; Pant, 2014). It is the notion that through collaboration and self-development people can have more power and autonomy. There are many definitions of autonomy but Christman’s (2009) definition simply highlights the crux of most interpretations:

‘Individual autonomy is an idea that is generally understood to refer to the capacity to be one’s own person, to live one’s life according to reasons and motives that are taken as one’s own and not the product of manipulative or distorting external forces’

Although in a different research context, the definition of autonomy provided by the British Medical Association is useful in understanding what it means as the outcome of empowerment. They say that,

‘two conditions are ordinarily required before a decision can be regarded as autonomous. The individual has to have the relevant internal capacities for self-government and has to be free from external constraints’ (BMA, 2019).

This suggests that autonomy is something which children are debarred from on the count that they do not necessarily have the internal capacities to make informed choices and they are not free from external constraints. It is therefore pertinent to consider whether the empowerment of a child is positive.

Nagel (2019) presents an argument against neuro-enhancement of children. They consider the pharmacological methods of enhancement alongside parental pressures to succeed using specialised coaches and tutors. Considering this perspective, the empowerment of a child could also be framed as a type of neuro-enhancement which is largely considered as unethical (Ibid, 2019; Garasic & Lavazza, 2016). Considering this provocation, it is appropriate to consider the empowerment of any group of disempowered individuals. Sing et al. (2009) say,

'The poor are entitled to rights- not only when working for others, but also in developing their own businesses…they are instrumental in poverty eradication and economic development.' (2009: 150)

When the empowerment of others is economically beneficial to the facilitators, the act should be viewed with a level of scepticism. Starting a business can be an empowering experience but it also puts the formerly disempowered in a position of perceived privilege where they no longer have access to the support previously available to them. This does not always lead to a positive outcome and the empowerment can instead be a method for reducing government responsibility for the impoverished. Considering the two arguments presented above the empowerment of an individual or group should be considered carefully to ensure that those who are being empowered are truly autonomous and have access to information and support to make that decision. In the case of children where it has been noted that they cannot have personal autonomy due to their stage of development, Van Der Kaap-Deeder et. al. (2016) present the notion of autonomy-supportive environments. These are spaces where people spending time with children are interested in the perspective and frame of reference of the child. This helps them to be aware of a child's desired choices and to encourage and support a child to take initiative and understand a situation in a way that is meaningful to the child. Perhaps autonomous supportive environments help children to be appropriately empowered at rate which suits their stage of development and awareness. Therefore, instead of being empowered as individuals, autonomous supportive environments could 'empower the principles of self-determination' (Sparrow, 2011).

As a summary of this nuanced interpretation of empowerment, this thesis will consider the empowerment of children as the provision of environments which help to develop a capacity for self-determination.

6.6 Conclusion

This review of literature was conducted in response to the 'soft' theories generated from analysis of the data. This chapter started with an exploration of art, craft and making before considering these as activities which can facilitate well-being. The ambiguity of these terms was highlighted and as such a working definition was developed from the literature. Research relating to 'The Maker Movement' was then reviewed and considered with regards to how making relates to the self, how it facilitates connection and how it has been studied in relation to children. A review of all known academic literature which discusses 3D printing pens was then conducted to highlight the disparity between the value placed on 3D printers compared to 3D printing pens. An overview of how making has been used in learning environments was then given which highlighted the need for a pedagogy of 3D printers. Song (2018) said that this was essential so that teachers can be confident in their understanding and use of technology while being able to effectively communicate the course content to their students. The concept of 21st Century Skills was then introduced to highlight skills considered essential for learners of the future, both digital and creative. Due to the significance of the capacity for making to be empowering, it was considered appropriate for power theories to be reviewed and highlighted to show how the experience of empowerment could alter an individual's perspective or priorities.

Chapter 7

7.1 Overview

This chapter will consider the findings and theoretical propositions of this thesis within the context of other research and studies based around 3D printing, making, children's learning and power constructs. The contextual grounding of the theoretical propositions will afford them additional rigour and make clearer their impact. The chapter will also provide clarity on their applicability to other contexts.

Design research is innately interdisciplinary and as such it lacks a shared tradition and consensus of research praxis. Redström (2017) argues that design should not strive to be like other academic disciplines or expect research findings to be consistent or valid over time. He instead suggests that theories from design research should be fluid and evolve so that they are relevant in alternative contexts. Design is fractured into practice and theory. However, design research can consider both positions and offers the unique capacity to make theory through practice; this can be interpreted literally as the ability to physically make theory or conceptually, to experience the proposed theory through the making of things. Redström (Ibid: 134-135) proposes a method for making theory in this way by first defining the proposition, then making this definition unstable before creating a composite definition which provides a conceptual structure on which to view and understand information.

Finally, this chapter will first provide a statement of the contributions to knowledge that this thesis provides. It will then elaborate on the five distinct theoretical propositions before considering how these can be transformed into design theories constructed using the method set out by Redström (Ibid).

7.2 Contribution statement

This thesis aimed to research the use of 3D printing in formal and informal education settings. The current state of knowledge within this area largely revolves around 3D printing and making for adults and the associated benefits of participation [28]. Additionally, it relies largely on the anecdotal observations of the educational potential of 3D printing for knowledge transmission (Chu et al., 2015)[29].

This thesis showed that the activity of participating in 3D printing and making led to increased confidence and the development of commonly acknowledged positive learning behaviours highlighted by Maltese et al., (2018) such as problem solving and peer learning. This thesis proposes that 3D printing as an activity has an intrinsic pedagogical property that has a positive impact derived from the experience of the activity in itself. This is a quality distinct from any predetermined learning objectives or prior conditions. 3D printing as a form of education praxis is thus not dependent on specific learning outcomes or prior knowledge. Likewise it is not conditional on participants positionality in terms of social background or previous attainment to be successful in the way described.

Studies such as those by Hatch (2014) and Cross (2001) present making as a leisure activity which is unproblematically accessible. This thesis questions these conclusions and in doing so offers a second contribution to the state of knowledge. This thesis suggests that while making is accessible to a degree, these activities are reliant on access through a gatekeeper, that is somebody with prior knowledge and access to these resources and this culture. This raises challenging questions around privilege and exclusion. With this in mind, this thesis highlights discussions of access to making in the literature before situating the data from this study within it to understand how the participants ended up engaged in a maker-based activity. The data suggests that motivation to access making for leisure can be conceptualised as social or learning based. This concept could be used in future studies surrounding access to making and in building communities around maker-spaces.

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[28] The benefits experienced by adults when participating in maker-based activities include an improved sense of well-being and a feeling of empowerment. These benefits are discussed further in Chapter 6, section 2.

[29] Making for knowledge transmission is discussed by Chu et al. (2015) to explain that making in education is often used as a mean to teach a particular subject rather than, as they argue the more powerful potential of using it as an activity to engage in and develop core self-development skills such as agency, self-determination and confidence.

The third contribution responds to the calls for a consensus and a framework for using 3D printers in the classroom (Chu et al., 2015; Nemorin & Selwyn, 2017; Song, 2018). Using the data collected in this study alongside the commonly cited prohibitive elements of classroom 3D printing (Nemorin, 2016; Nemorin & Selwyn, 2017) this thesis contributes an early step in the development of this framework by providing a lesson plan outline (Appendix 7) which has proven successful in the author's own practice to suggest how a consensus on the pedagogy of 3D printing may be developed and achieved.

The final contribution relates to risk tolerance in children. The existing literature highlights the importance of children experiencing risk so that they may learn to navigate it appropriately (Munro & Tanaka, 2016). Through consistent observations, the data shows that 3D printing and maker-based learning allow children to experience risk and challenge rules by giving them access to real tools. This allows them to develop an informed understanding of the logic behind the rules imposed on them. This probing of boundaries is a recognised as a positive and necessary stage of development (ibid, 2016). Providing this opportunity within classrooms allows for the provision of autonomy supportive development environments.

7.3 Motivation for making

7.3.1 Overview

Making is widely regarded as having a positive impact on well-being (Peppler et al., 2016; Gauntlett, 2016; Ratto, 2011; Sennett, 2009). It is attributed with making people feel empowered through a developed awareness of self-efficacy, fulfilled through a type of liberation and giving people the skills and critical thinking necessary to challenge their own ideas and prejudices (Anderson, 2013; Adamson, 2007; Crawford, 2009). However, despite these positive behaviours established by engaging in the making process, making requires effort and resources to take part. This effort can range from simply deciding to make something to the planning of an elaborate project. The resources for such making can be anything from leftover packaging to expensive electronic kits. Despite this seemingly democratic access to making where anyone can participate regardless of their personal circumstances, the benefits experienced through participation are dependent on motivation. The benefits described in existing research and the findings proposed in this thesis relate only to the participation in making as a leisure activity. Therefore, participation in making when it is required, for example for survival, livelihood, or for passing a test cannot be proven to have the benefits associated with making for leisure. This thesis therefore argues that there should be a clearer definition of types of making. Furthermore, it argues that the notion that making is accessible for all is challenged to improve opportunities of making for leisure so that it truly can be experienced by anyone. Access to making for leisure currently relies on prior knowledge or experience of making for leisure and those who have neither are debarred from access to making, making the pursuit inherently undemocratic. This argument will be developed further throughout this section before considering what the motivations were for the children attending the workshops delivered through this research and how this can advise on a democratic approach to engaging people in the making process.

7.3.2 Essential making vs. making for leisure

Motivation was described in Chapter 6 by showing the experience that people have when engaged in making and how the theory of self-determination explains that making satisfies the three recognised required factors for fulfilment as autonomy, relatedness and competence (Rusk in Peppler et al., 2016: 97). Hatch (2014: 1) describes making as a fundamental activity, which humans are inclined to participate in and there is a call to action from Leadbeater (2009) who argues that people should create more and consume less. However, it could be considered that the type of making that people do out of necessity, that is making tools and essential objects for survival, is different from the type of making which provides people with the empowerment, fulfilment and personal development as described by Crawford (2009) and Anderson (2013). Ruskin (1863) and Morris (1884) discuss the concept of useful work as something which provides people with the feeling of productivity and achievement which contributes to well-being. Since the industrial revolution there has been less demand for people to do ‘useful’ work and as such it has become romanticised (Frayling, 2011). When it is not necessary to take part in an activity it can become more enjoyable to do and the time spent doing it allows for self-reflection which can lead to the reification of the experienced benefits. This should be kept in mind when considering how prescriptive maker tasks are set in schools which become a type of necessary work for the participants and therefore risk eliminating the associated benefits of making for leisure.

The persistent reference to making as a fundamental human behaviour (Arendt, 1998: 91; Ingold, 2013; Cross, 1982) therefore perhaps conceptually compresses the idiosyncrasies of the making process. Making is an activity that humans may always have participated in but the motivation for doing so has varied dramatically. The types of making proposed by 'The Maker Movement' (Hatch, 2014) is motivated by the desire to engage in the process of making. This does not mean that the outcome of the making cannot be useful or necessary but engagement in the process is key to the motivation for participating (Gauntlett, 2016). Additionally, if the outcome of this activity was useful then it would have been necessary for the maker to believe that they had the capacity to create the object and therefore indicated that they were already aware of their self-efficacy. This suggests that participants in 'The Maker Movement' are already empowered enough to take part, either by personal desire or by being involved through a community group or organisation. This becomes problematic as making as a leisure activity and associated maker communities are positioned as inclusive and democratic. However, access requires a level of prior knowledge or a gatekeeper to signpost participants to opportunities and is therefore by definition undemocratic. To expand on this, it is pertinent to consider those who are not self-identified makers and who are not involved with making in any capacity. Opportunities to participate in making for leisure are dependent on being exposed to this as an activity in some capacity either through acquaintances or by having a personal desire to learn or make something. The suggestion that making for leisure, and therefore the associated benefits of such, is available for everyone is dubious. This notion relates to the art therapy research discussed in Chapter 6 (section 6.2.2) where it was noted that the studies on art making for improved well-being did not clarify whether the participants were already inclined to participate in art making prior to the study. This further supports the argument presented in this thesis that it cannot be assumed that everyone wants to or has the opportunity to participate in an activity even if, from a practical point of view, they have everything necessary to successfully participate. One would have to have the knowledge of and an inclination towards making for leisure before they could participate and experience the associated benefits. Therefore, it is important to highlight this discrepancy in maker literature. Without recognition of the distinction in types of making it is easy to get absorbed in the experience of making for leisure and forget that making may also be required for necessity. This is not as widely known about or engaged with, as the literature may suggest.

It is therefore necessary to consider how to engage people in making for leisure so that they too may benefit from the associated advantages. There are many descriptions from the literature (Anderson 2013; Crawford, 2010) of people describing fond memories of tinkering in the garage with their father or grandfather, which resulted in them wanting to re-engage with their hobbies. However, as is also described (Anderson, 2013) the number of grandparents and parents who tinker in the garage is not as common as it once was and so the number of people who inherit skills from family members is decreasing (Ibid, 2013). This loss of generational knowledge transfer will widen the gap between those who have access and power to engage in making and those who do not which reifies the empowerment and disempowerment differences between the groups.

7.3.3 Data in context

The findings of this research can be considered with reference to the different types of making. Firstly, the 3D printing workshops delivered as part of this study attracted a range of children and young people from all backgrounds, including hard to reach children. In practice, the provision of maker-based workshops for children of all sections of society helps to provide all attending children and young people with the knowledge and some experience of making. As children and young people, they may not have an awareness of the person they may be expected to become as predetermined by their social status and ability. Therefore, participation in making provides the opportunity to adjust the notion of predetermined expectations relating to attainment based on social class before these notions have been accepted by the individual. 3D printing workshops in this study resulted in a recorded awareness of agency and self-efficacy in 45% of workshops, 39% in type D workshops[30]. This shows that the provision of maker-education for all children offers the opportunity

[30] Type D workshops were typically provided to marginalised children and young people, many of whom experienced poverty.

for children to experience making and therefore have life-long access to the practice through awareness and witnessed benefits. There is an agreement among many maker researchers that opportunities for making in childhood contributes to the development of curiosity which impacts the way they interact with the world around them (Schön et al., 2014; Gershenfeld, 2007).

In terms of the findings regarding motivation for attending 3D printing workshops based on the recorded exhibited behaviours, there were two independent factors shown to be influential in the participation and active engagement in these workshops. These were learning-based behaviours and social-based behaviours. The data shows that Type A workshops illustrated the highest number of instances of all six defined behaviours[31]. This was thought to indicate that participant attendance was motivated by the desire to learn the skills on offer at these workshops. Kealy-Morris (2015) explains that participation in a craft workshop she facilitated increased confidence by developing a creative identity within participants who enjoyed spending time creating in the presence of other like-minded people. This would suggest that the finding of this research, that children attending a workshop motivated by developing a skill would also develop a self-awareness of their identity as a maker who spends time with other makers. This perhaps offers an insight into the particular success of developing and exhibiting all defined behaviours and skills in a type A workshop. The participants were able to experience and benefit from their engagement with 3D printing as well as the time they spent with other children with similar interests and motivations.

Type B workshops, which were attended by a group of friends, were noted as being most conducive to social based behaviours where learning was positioned as secondary to the opportunity to spend time socialising with friends. Salvy et al. (2012) discuss the influence of peers on participation in different activities. Their general findings regarding the correlation between peer influence and decision making concurs with the data of this study that suggests that social-based behaviours are more prominent within type B workshops than learning-based behaviours. This

[31] Defined behaviours were problem solving, social learning, experience of agency, communication with peers about themselves, expression of pride in achievement and satisfaction with outcome.

indicates that motivation to attend largely depends on peers and group decision making.

Type C workshops showed that 3D printing workshops taking place within a school-based setting were more likely to result in the exhibition of learning-based behaviours including problem solving and social learning. Type C workshops were the least conducive to social-based behaviours which included communication with peers about themselves and an expression of pride in their achievement. This would indicate that when situated within a place where children expect to adhere to particular rules and structures the full range of benefits associated with making can be affected. This means that children who attend 3D printing workshop within their school classroom treat the workshop as they would a school lesson and as such their motivation and focus is on learning rather than socialising with other participants. Additionally, the children attending were all known to each other as they were in the same year at school. This provides an insight into how 3D printing workshops could be received within formal learning environments as opposed to the informal environments explored within this study. However, it should be remembered that the type C workshops of this study took place within a private school where it could be argued there is a greater focus on measured achievement (Anand et al., 2009). This may introduce a bias towards how children interact with new technologies and learning opportunities where they are motivated by teacher and parental approval of their performance before their own curiosity or experience with others in the classroom. In discussing perseverance with music skills development Halpin (1990) notes that academic success was prioritised over social integration at private school. This concurs with the proposition that type C workshops are less likely to be attended by children motivated by the social value of 3D printing and making as an activity. However, the data does not give a clear indication of how these workshops could be received in a formal learning setting within a state school.

An ethnographic study conducted over 5 years with thousands of young people in youth clubs identifies a dominant factor which influences how young people behave as 'how they are seen by others', they must maintain their identity as one of the group who deserves respect (Heath and Mclaughlin, 1993). This study supports the data provided within the research of this thesis as learning and social based behaviours all occur less within type D workshops than in the other workshop types. Type D workshops were provided within existing social groups and as such attendance was motivated by routine of attending the youth club and the provision of a hot meal. Participants could then choose to take part in 3D printing workshops. The statistical analysis indicates that the motivation to participate was not social-based. However, the qualitative data shows that children and young people were taking part in workshops because their friends were, as can be seen in the following example:

> 'some girls came in to see the boys and weren't interested in the printer or pens at all until one of the boys told a girl to have a shot of his pen. Once she tried the pen, she asked for her own and the girls joined in.' (Appendix 3: diary entry 136)

The contradiction of the qualitative data compared to the statistical analysis can be explained by the complex dynamic of a youth club. Only 14% of type D workshops were shown to be conducive to having participants talk to others about themselves which was one of the behaviours defined in this study as indicative of social motivation for participating. However, participants at a youth club can be self-conscious and unwilling to put themselves in a position of vulnerability (Diamond et al., 2016) in the sometimes hostile and chaotic environment where adolescents interact with each other in large numbers. This indicates that when providing access to 3D printing and other maker technologies within a youth club setting, the expectations of what skills can be developed should be considered in relation to the specific complexities associated with youth club dynamics.

This thesis proposes that provision of access to maker-based learning should be available to all children in their education to give them the opportunity to witness their own capacity. However, expectations of the associated benefits should be measured in relation to the type of setting it is to be implemented in, as well as considering the motivation of the participants. Additionally, in cases where people do not have knowledge or experience of making as a leisure activity, access can be promoted by citing the motivation for participation by others. As demonstrated in the data of this study, making may provide an opportunity to socialise or an opportunity to learn a new skill.

7.3.4 Concluding comments

To conclude this section, it was shown that participation in making for leisure requires prior knowledge or experience of this type of making for participants to experience the associated benefits of making for leisure. Additionally, it was shown through the literature that making is an activity fundamental to humans (Hatch, 2014; Gauntlett, 2016). However, this assertion does not address the experiential differences of making out of necessity and making for leisure. Therefore, it is pertinent to acknowledge the knowledge gap between experienced makers and less experienced makers so that it can be narrowed. This is particularly important due to the decreasing generational knowledge transmission of tinkering and making things (Anderson, 2013). The data provided in this thesis suggests that the provision of maker-experiences in early education can prevent notions of pre-determined attainment by providing opportunity for children to witness their capacity. Additionally, this thesis provides the empirical data which supports the idea that engagement in making is motivated by the desire to learn a new skill or to socialise with friends and likeminded people. The proposition that participation in making for leisure is motivated by one of two distinct categories contributes a new perspective on understanding why people make. Furthermore, caution should be exercised when using making in order to achieve a predetermined goal, for example using making to teach particular information. If the children are not motivated by the making itself the outcome could be disappointing and potentially damaging to the perception of making as a leisure activity by the individual.

7.4 21st Century skills highlighted by The Harvard Advanced Leadership Initiative (2014)

7.4.1 Overview

Rapid advances in technology have led to significant changes in the way that children learn. Online resources provide alternative means of gaining knowledge from a range of sources and perspectives (Vettese et al., 2016). Schools will likely struggle to keep up with these advances. Therefore, instead of focusing on the material to be taught, it could be argued that the primary role of schools in the 21st century is to provide children and young people with the opportunity to develop skills necessary to succeed. The research presented in this study shows the exhibited behaviours observed in 3D printing workshops which were delivered to children and young people from different backgrounds in a Scottish context. The exhibited behaviours correlate closely with the findings of positions papers and reports which advocate for the development of these skills (Harvard Advanced Leadership Initiative, 2014) in schools.

7.4.2 21st Century Skills

Ford and Minshal (2019) explain that, 'there are concerns that education and skills development lags behind these technical developments and that they may inhibit the technology's wider adoption' (2019:31). Additionally, because schools have a delayed uptake of findings from current research and due to the scale of the task of implementing curriculum and policy change, some teaching methods are counter-productive to behaviours of curiosity and a natural desire to learn, which young children exhibit (Harvard Advanced Leadership Initiative, 2014). Lipsom and Kurman (2012) say that children are often discouraged from being curious and carrying out their own experiments by teachers and schools who are focused on a rigid curriculum which leaves little time for divergences from task. Robinson (2015) says alternative and creative approaches are necessary to teach children in this century. Reimer et al. (in Harvard Advanced Leadership Initiative, 2014) indicates that areas where schools are failing are global citizenship development and awareness, poor connections between levels of education, standardised testing and poor teacher evaluation. The Harvard Advanced Leadership Initiative report (2014) says that to improve in these areas, schools need to be developing the following skills in their students: critical thinking and problem solving, creativity and innovation, collaboration, question formulation, global awareness, communication skills and technology skills. The report says that the following skills are desirable: entrepreneurial skills, financial literacy, life skills, people skills, self-direction, personal and social responsibility, and character and citizenship. The labels given to these skills vary in each study, but the meaning is the same. Trust and Malloy (2017) draw parallels between 21st Century skills highlighted above, and the observed skills developed through 3D printing projects in schools. They presented their data in a graph shown in figure 3.

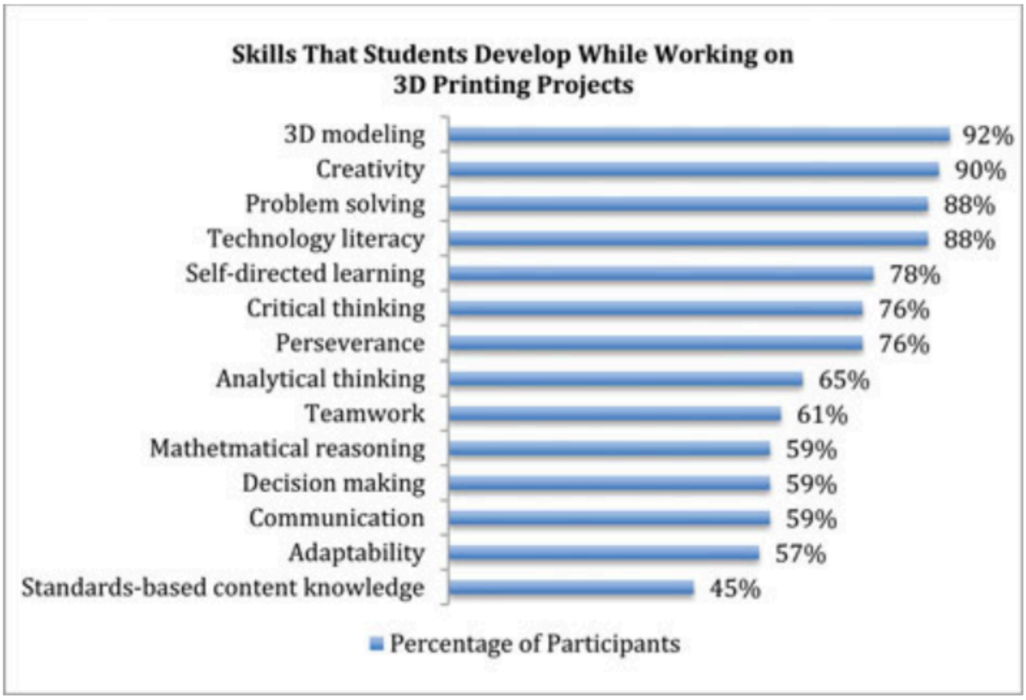

Figure 3 Data from survey carried out by Trust and Malloy (2017)

This graph shows that children developed a number of skills which fall under the defined necessary 21st Century skills. The data shows that of 61 teachers surveyed who use 3D printing in their teaching, 61% of them believed that their students engaged in team-work, 90% of them used creativity, 76% showed critical thinking, 88% felt that their students engaged in problem solving and 57% thought that their students showed adaptability. In the context of the data collected for this study, it should be made clear that these percentages refer to the number of teachers who believed that 3D printing engaged students in these skills.

7.4.3 Collected data in context

The verification study data presented in this thesis shows that 85% of participants in 3D printing workshops were observed to engage in problem solving and 100% of workshops were shown to include problem solving behaviour. Team-work was defined in this thesis as when children actively worked together on a project and was not tested in the verification study due to insufficient evidence in stage 1 research. However, if the definition of team-work as a skill included asking for or offering advice between peers then this thesis shows that 48% of participants engaged in this skill with 100% of workshops having social learning occur. The other skills mentioned by Trust and Malloy (2017) in their data do not correlate directly with the data presented in this thesis. However, an expression of pride in achievement could be considered relevant to the communication skill and the 'personal and social responsibility' skill as children recognise that the hard work which led to their achievement was the result of them taking responsibility for their own projects. This occurred in 100% of workshops. The opportunity to communicate with peers about themselves would fall under the communication skills category and the data of this thesis showed that 100% of workshops showed this behaviour occurring with 52% of participants developing their communication skills. Experience of agency is a behaviour which could indicate a range of skills including, critical thinking, global awareness of self-efficacy and the capacity of others. 100% of workshops were observed to be conducive to experiences of agency. However, only 45% of participants were identified as experiencing this. Finally, a satisfaction in the outcome of a 3D printing workshop does not directly correlate to any of the defined 21st Century skills, although it does show that children have employed their technology skills.

The data shows that maker-based education is fertile for the development of 21st Century skills as defined by the Harvard Advanced Leadership Initiative (2014). All common behaviours shown through the data in this thesis have some correlation with the defined skills. This therefore suggests that 3D printing workshops are suitable environments for learners to overcome challenges presented in current education. The study by Trust and Malloy (2017) is substantiated significantly with empirical data which shows that both 3D printers as a tool and 3D printing workshops alongside 3D printing pens are conducive to a suitable learning environment for 21st Century learners.

7.4.4 Concluding remarks

Educational institutions struggle to stay up to date with advances in technology and require a creative approach to teaching to ensure that children learn the necessary core knowledge, as well as develop characteristics considered essential for success in the 21st Century (Harvard Advanced Leadership Initiative, 2014). A set of skills have been defined by a steering group of academics which can be used as a criterion for the design of a new pedagogy for learning (Ibid, 2014). Trust and Malloy (2017) provide data which shows that teachers believe that skills which correlate with the defined 21st Century skills are developed by students who engage with 3D printing in school. This thesis contributes a substantial qualitative and empirical study based on the observation of more that 3000 children and young people to this field. The data in this thesis agrees with the data presented by Trust and Malloy (2017), while adding several more behaviours to the list which can be interpreted as fitting into each skill or category defined as essential for 21st Century learners. This thesis argues that maker-based learning is an option for teachers looking to transform their practice to meet the demands of learners in the 21st Century.

7.5 The potential of making to facilitate autonomy development in children

7.5.1 Overview

This section will consider the role that making can have in the development of autonomy in childhood. Studies suggest that it is important for children to learn about risk and how much is appropriate (Munro & Tanaka, 2016; Briggs, 2018). Van Der Kaap-Deeder et. al. (2016) describe the importance of providing autonomy-supportive environments to help children learn to be empowered. Data from this thesis shows that making can provide opportunities for children to experience danger and challenge rules they perceive as arbitrary, and to take responsibility for their own agency in this.

7.5.2 Recognition of importance of risk awareness in children

Munro and Tanaka's (2016) study shows that children are less risk averse than their parents but more loss averse. This suggests that children will balance risk by considering what could be lost whereas parents are more concerned by risk in general. Briggs (2018) says that children have more decision-making power than in the past and that this is due to parental reluctance to be authoritarian, with a concomitant tendency towards permissiveness. She argues that in the absence of guidelines and boundaries children can develop feelings of insecurity. She says that ways to prepare children for decision making is by developing a child's confidence and awareness of their rights and responsibilities (2018:3). When testing one of Montessori's theories about giving children the option of carrying out 'pretend or real-world' activities Taggart et al. (2018) noted that most children chose to do the real-world activities. Children who chose the pretend activities cited their reason as being too afraid or that they were not allowed. Therefore, it could be suggested that real-world activities develop a child's sense of responsibility and self-confidence.

7.5.3 Evidence in the collected data which contextualises positive autonomy development

An observation of children making rings by using the 3D printing pens to wind plastic around their gloved fingers (diary entry 79) demonstrates an instance where a 3D printing workshop facilitated risk tolerance in children. The research-facilitator said to the participants that it would be too hot and burn them, however the participants decided that this was not the case and proceeded. If the melted plastic had been burning them they would not have been able to continue and therefore the participants challenged the researcher-facilitator's advice and ascertained that this did not apply to them. This demonstrates the benefits of experiencing controlled risk in a supervised environment. By allowing children to play with tools which they know are potentially dangerous, the children felt trusted and took responsibility for their safety. This provided the opportunity for mutual trust to be developed where both parties were positioned as equals. This helped to diminish the unbalanced power constructs which can exist in educational environments.

Another observation of children challenging rules was when a participant made a fidget spinner. This participant's mother had forbidden this child from having a fidget spinner which was a popular toy at the time. When this child saw other children making fidget spinners she was excited to make her own. She said that if she made it her mother would not take it from her. This scenario could be considered as problematic as the child was disregarding a rule set by her mother who has legal responsibility for her. However, by making this forbidden toy, the girl was challenging the rule which she viewed as arbitrary which could help to prompt a conversation where the mother could explain to the child why the toy was forbidden. A study by Van Der Kaap-Deeder et. al. (2016) supports this as a valid method for providing children with the opportunity to challenge rules and boundaries which helps to develop their own ability to evaluate a situation and make decisions based on the evidence available.

7.5.4 Concluding thoughts

To conclude this section, the importance of children being aware of and understanding risk and rules was highlighted by citing the works of Munro and Tanaka (2016), Briggs (2018) and Van Der Kaap-Deeder et al. (2016). Children must learn to evaluate risk and rules in order to navigate their interactions with people and the environment around them. Data from this study shows that when engaged in maker processes, children are afforded the use of digital fabrication tools which can be dangerous to use and provided opportunities to create forbidden objects. Having access to these tools and the associated capabilities gives children responsibility and demonstrates a level of trust by the educator which helps the children to view themselves as capable individuals.

7.6 Evidence of impediments to integrating 3D printing into education

7.6.1 Overview

Making, in particular, 3D printing has been hailed as the new technology which is going to transform education (Gershenfeld, 2007; Anderson, 2013). There is an assumption that because the technology has qualities which enable children to better engage with problem-based learning (PBL) which is considered one of the most successful learning methods (Harel & Papert, 1991), by having one in the classroom children will necessarily experience the associated benefits of maker or PBL education. However, as with all technologies, they can only perform to their potential when integrated as part of a wider system to make them relevant and accessible. There is evidence from studies which suggests that 3D printing classroom-based projects are not as successful as expected due to the limitations of the technology (Nemorin & Selwyn, 2017). However, based on the observation of 3011 participants through 247 workshops, this thesis argues that the limitations experienced in the published studies were primarily a result of teacher inexperience. Although the technology has limitations, these can be overcome in a classroom setting to provide a successful and deep learning experience.

7.6.2 Potential of 3D printing in education

3D printers have been enthusiastically embraced as an exciting new tool to support learning in classrooms (Gershenfeld, 2007). STEM is the main area in which teachers are envisioning potential to allow their students to learn about the subject material through playing with tools and physical objects of their own design (Irwin et al., 2014). However, there are reports of 3D printers being used in all areas of education. A study by Song (2018) suggests that there is an assumption that technology automatically makes teaching more successful. She argues that there is a lack of pedagogy to contextualise 3D printers in a meaningful way and until there is a widely recognised way of promoting and using 3D printers with students, teachers must rely on professionals to integrate 3D printers into education. Nemorin and Selwyn (2017) highlight a lack of resources for teachers to successfully integrate 3D printers into their lessons. Additionally, Resnick et al. (2016) warn that by situating 3D printers and other making tools as a means to provide children with an opportunity to learn set material using a 'learning through doing' approach as advocated by Harel & Papert (1991) and Piaget (in Boden, 1988), there is a risk that the potential benefits of simply engaging in the process of making, will be overlooked. The opportunity to make for the sake of making is necessary so that children can develop self-directed learning skills alongside the other aforementioned advantages of a maker mindset (Dougherty, 2016).

7.6.3 Evidence of impediments to using 3D printers in education

Nemorin (2016) and Nemorin and Selwyn (2017) provide detailed observation and analysis of a 3D printing-based project in a classroom. Nemorin (2016) visited a high school which had recently acquired a 3D printer. She interviewed the teacher who explained that he was enthusiastic about the potential of 3D printers to provide learning opportunities but confessed that he was a novice hobbyist who had never previously actively used a 3D printer. He got funding from the school, bought a 3D printer after researching the suitable options and took it home for a few weeks to learn how to use it. He then designed a 12-week project where his students were expected to make a race car which could be fitted with electronics to make it move. At the end of the 12 weeks there was to be a race with everybody's cars. Nemorin (Ibid) participated in the class and went through the process of ideation, design, CAD modelling, printing and finishing along with the other students. She described her personal experience of excitement, then frustration with CAD modelling and disappointment in the slowness of the production. Her experiences are shown to be similar to those of other students. Nemorin (Ibid) argues that failure within making is valorised but that lived experience is disheartening. Nemorin (Ibid) and Nemorin and

Selwyn (2017) suggest that 3D printing used in education provides a different experience to those of making taking place in maker spaces. They say that 3D printing can be used as a knowledge building tool but that it has the pitfalls of previous technologies attempted to be used in school and that 3D printing cannot be considered uncritically as a way to reimagine school lessons. They suggest that empirical studies are necessary to give a fuller understanding of how making can be used in k-12[32] education and what learning objectives can be achieved.

7.6.4 Data collected relating to maker-projects in education settings

This thesis provides qualitative and empirical data which provides a broad and specific overview of how making can be used in education settings. Nemorin (2016) highlights the age range evaluated within their study as k-12 which translated into British education is nursery school up until the final year of secondary school. Her observations were based on children aged 11-13. The data from this thesis mainly covers the age range 6-18 with 8-12 years being the median range and therefore the age of children observed is similar to Nemorin (2016) and Nemorin and Selwyn (2017) and as such comparisons can be drawn between application and results of 3D printing within education.

The problems cited by Nemorin (2016) were: that the CAD process was frustrating to use and required a steep learning curve, 3D printers were slow, and results did not match the expectations of students due to errors made in the design process. These problems are common to all experiences of making (Maltese, 2018) and therefore the conclusion that experience of making in a classroom was different to making within a makerspace could be challenged. However, a makerspace does offer the almost limitless opportunities for iterations and as such, failure and mismanaged expectations tend not to be the end point of the making process in a makerspace (Ibid, 2018) which does alter the end point experience afforded in classroom settings with the type of project-based learning described by Nemorin (2016).

The workshops delivered as part of this thesis were facilitated by an experienced facilitator who has spent several years adjusting workshop structures to avoid the

[32] K-12 is an American expression to describe nursery school to aged 18.

pitfalls described by Nemorin (Ibid). The qualitative data shows that the use of CAD is not necessary within the workshops but that children can choose to use it. As discussed in section 7.3 when someone is required to do something in order to achieve a predetermined, unmoveable goal, the activity becomes less enjoyable and is conceptualised as hard work (Doke & Risley, 1972). However, the children who chose to use CAD in the workshops studied in this thesis, were provided with a brief demonstration of how to use the basic tools and were left to explore the software. Additionally, because the children were using CAD as a tool to play with, they tended not to have a fixed vision of what they wanted to achieve. Therefore, their designs were inspired by their spontaneous play with the software. Evidence of the success of unstructured approaches to learning software has been demonstrated in other studies by the author of this thesis (Allan, 2017; Vettese et al., 2016). 3D printing pens were used in classes observed by Nemorin (2016). However, they were used as a way of adding details onto the surface of the 3D printed model. The workshops delivered for this thesis rely heavily on the use of 3D printing pens. They provide the opportunity for children to create designs and models quickly and therefore afford the iteration required to produce successful models. Additionally, they help to give children a tangible means of understanding how the 3D printer works while also conveying the benefits of each tool. 3D printing pens are fast, allow for ideation and iterative designing but cannot compete with the 3D printer in terms of quality of finish. Therefore, this thesis argues that 3D printing pens should be used as a prototyping tool when using 3D printers in a classroom setting. They provide a low-cost and accessible means of developing a maker mindset and the opportunity to experience the advantages associated with making as described in section 7.3.

Limitations of 3D printers in classroom identified by Nemorin (2016).	Methods for overcoming these limitations of using 3D printers in classroom demonstrated in this thesis.
CAD process was frustrating	CAD learning was child led and allowed them to explore tools within the software with no formal objective set.
3D printer is too slow	Use 3D printing pens to ideate and create prototypes which allows children to create models in minutes rather than hours.
Results did not match expectations	Children used 3D printing pens to create prototypes which allow them to overcome design flaws which meant that 3D printed models were more successful. Additionally, 3D printing pens produce a lower quality of finish and so models that were 3D printed had a higher quality finish than they were used to and as such children tended to be more impressed by what they made.

Table 25 Limitations of using 3D printers in classrooms and how to overcome them.

The empirical data of this thesis show that virtually all participants observed within the verification research presented in this thesis were satisfied with what they made within the 3D printing workshop. This shows that by having a flexible approach to tools used, participants take responsibility for what they make and even if it does not match their expectations they understand why and take personal responsibility for it and as a result are happy with the outcome of the workshop.

Therefore, despite the limitations described by Nemorin (2016) and Nemorin and Selwyn (2017), being consistent with the findings of others (Maltese, 2018) that CAD is frustrating to learn as a beginner, 3D printers are slow, and expectations cannot be met with the outcome. This thesis argues that these limitations can be overcome by adopting a different approach to project implementation as shown in table 25. The teacher described by Nemorin (2016) was enthusiastic and passionate about engaging his students with 3D printing. However, his lack of experience meant he did not anticipate problems that are virtually inevitable. Therefore, it could be argued that the findings proposed by Nemorin (2016) and Nemorin and Selwyn (2017) were significantly influenced by inadequate teacher knowledge and resources. This suggests that for successful implementation of 3D printers into classrooms teachers must be better supported and provided with a guide to aid their success. In response to this a sample 12-week lesson plan has been created using the data from this thesis which can be used by teachers to enable children to become competent in the following areas: creating prototypes, beginner level CAD modelling and operation of a 3D printer. This lesson plan can be found in appendix 7.

7.6.5 Concluding remarks

To conclude this section, it has been shown that 3D printing and making is elevated in literature and media as a potentially revolutionary learning device (Lipson & Kurman, 2012). However, most reported uses of it within education is a means of knowledge transmission for STEM based subjects (Irwin et al., 2014). This appropriation of making for this purpose denies the makers access to the potential advantages which they can experience through free-making. Additionally, the studies available which describe the implementation of 3D printing-based projects in education are facilitated by teachers who lack the experience necessary for teachers to anticipate problems associated with 3D printers. Therefore, this thesis argues that in order to successfully implement making into classroom projects it is necessary for teachers to have adequate experience of using the technology so that they are able to provide guidance and workarounds when their students are confronted with problems. The data put forward in this thesis supports the idea of making as an activity in and of itself. The setting of predetermined and well-defined learning outcomes impedes the learning and self-development which can be achieved when students have the freedom to choose which tools they use and to what end. However, the author does acknowledge that where learning outcomes are essential for standardised education free-making may not always be a realistic option. In this case, the author advocates that the teachers provide multiple approaches to achieving the set outcomes. It is proposed that should Nemorin's (2016) study be carried out again with greater value placed on 3D printing pens to create prototypes, the outcome in terms of expectation and satisfaction would be improved which is a proposition supported by the satisfaction experienced by the participants of workshops in this study. Finally, a sample 12-week lesson plan has been created (see appendix 7) using the findings of this thesis in the context of the classes described in the studies by Nemorin (2016) and Nemorin and Selwyn (2017).

7.7 The advocation of 3D printing pens as a serious and accessible tool for maker education

7.7.1 Overview

3D printing pens are hand-held tools which can extrude melted plastic to create solid objects on a piece of paper or in the air. They are predominantly marketed as toys for children (Amazon, 2019). However, there are some brands such as Lix (Lixpen, 2019), which are advertised to architects and designers, though there is no recorded use of this purpose within academic literature. There are five known studies aside from those which the author of this thesis conducted or contributed to and within these, 3D printing pens are always positioned as additional tools which compliment a 3D printing workshop. This thesis argues that 3D printing pens are significant tools which can be used to provide low-cost access to a maker mindset. Additionally, the findings of this study suggest that 3D printing pens can be used as an art medium. Further, despite the figures showing that girls typically participate more in art activities than boys as children and adolescents (Etherington, 2008), participation by boys in the first stage of this research[33] is significantly higher than that by girls with 58.3% of all participants being male and 41.7% of participants being female.

7.7.2 Evidence of 3D printing pens being used in makerspaces or schools in existing literature

Dean et al. (2016) highlights one way in which 3D printing pens have been used successfully within education settings. Their first-year university students were provided with 3D printing pens to create scientific models which are difficult to imagine without seeing the three-dimensional structure. Imeri et al (2017) provides an evaluation of 3D printing pens for use in k-12 in education citing that children can

[33] Gender was not recorded in the confirmation research.

develop hands on learning skills. Hancock (2015) however, describes the use of 3D printing pens as part of an outreach programme associated with a museum exhibit as ‘complimentary to the activity’. This shows that in this case, the 3D printing pens were considered as additional and not considered to be as significant as a 3D printer. Nemorin (2016) also discusses 3D printing pens as additional and says that children could use these to decorate their 3D printed model. With the exception of Dean’s et al. (2016) study and Imeri’s et al (2017) evaluation, all the evidence of 3D printing pens in literature other than that of the author of this thesis, show that 3D printing pens are not considered a serious tool. Additionally, on the list of essential equipment which Gershenfeld (2007) recommends for a makerspace, 3D printing pens are not included. However, despite the seemingly hesitant response to 3D printing pens, they do appear to fit the criteria for what Eisenberg (2013) said would help to make 3D printing technology more accessible which was a portable 3D printing device, or a tool designed for hand-customisation.

7.7.3 3D printing pens as significant tools

3D printing pens were used alongside a 3D printer in the workshops developed as part of this research. However, 3D printing pens were used significantly more than the 3D printer itself. 3D printing pens provided children with a tangible way to create models of their ideas quickly. They allowed the participants to develop an understanding of how a 3D printer works, as well as to learn other skills such as spatial awareness, measurements and engineering based concepts such as tension and weight.

Makerspaces typically have many tools including 3D printers, laser cutters, CNC machines, prototyping electronics and more (Gershenfeld, 2007). However, the skills developed in these spaces are defined as the same as, or similar to, the skills exhibited in the data from this study. Thomas (2014) defines makers as having: curiosity, playfulness, risk, responsibility, persistence, resourcefulness, generosity and optimism. All of these characteristics can be seen through the qualitative observation-based diary entries and this therefore suggests that 3D printing pens provide similar opportunities and associated benefits to other digital fabrication tools.

The use of 3D printing pens led to the following exhibited behaviours: problem solving, social learning, expression of pride in achievement, communication with peers about themselves, experience of agency and satisfaction with outcome. In the verification research, the following percentage of total workshop participants were shown to have exhibited these behaviours.

Exhibited behaviour	Percentage of participants who exhibited the corresponding exhibited behaviour.
Problem solving	85%
Social learning	48%
Expression of pride in achievement	41%
Took the opportunity to talk to peers about themselves	52%
Experience personal agency	45%
Expressed satisfaction with outcome	100%

Table 26 Percentage of participants who exhibited defined behaviours

All of the exhibited behaviours described above are common to makers. Problem solving can be considered as requiring individuals to be 'resourceful and persistent' which were defined by Thomas (2014) as maker characteristics. Social learning was discussed by Maltese et al. (2018) regarding making as a means of learning and being inspired by peers. An expression of pride in achievement was often characterised within the diary entries as the desire to show others what they had made, which is considered a key trait in making, to share success and failure stories with others (Hatch, 2014:1). Communication with peers about themselves is another key behaviour of makers as Hatch (2014:28) describes makers as seeking support and companionship with others. Experience of agency is one of the most widely recognised outcomes of making (Oxman in Peppler et al., 2016: 37). Finally, satisfaction with outcome can simply indicate that the participants were pleased with their experiences and what they took home. Makers engage in the process because it is enjoyable and even if the outcome is not perfect or what was imagined, it signifies the process that was engaged in to create it (Rafalow in Peppler et al., 2016) and the maker will be satisfied with the outcome of having engaged in the process.

This subsection has shown that 3D printing pens are valuable tools and can offer the experiences provided by tools of digital fabrication while being a low-cost alternative.

7.7.4 3D printing pens as an art medium

3D printing pens are described in the advertising copy as being for artists, designers and makers (3Doodler, 2019). The observations provided in the diary entries (See appendix 4) provide many examples of children using 3D printing pens to make models, pictures and as a tool to illustrate their story or idea. This advertising copy and observations suggest that pens can be considered as an art-making tool. When children use the 3D printing pens they are described as 'drawing with them' which highlights the conceptualisation of it as a tool to create something that could be considered as art. Titus and Sinacore (2013) say that art making is becoming increasingly recognised as positively impacting physical, mental and emotional well-being and is used effectively in art therapy. 3D printing pens as a tool capable of art making can also positively impact emotional well-being as shown in the data where children experience agency and are happy with their experience. Russo & Sobel (1981) describe the inequality in access and representation within mental health services, explaining that women receive better treatment for their disorders. Rice et al (2018) say that men are less likely to seek treatment for their mental health with the greatest barriers being adherence to male stereotypes and unfamiliarity with types of therapy used. 58.3% of participants in this thesis were males who attended the workshops. This suggests that making using 3D printing pens could be offered as an alternative to art therapy. Etherington (2008) said that boys were less likely to participate in art making than girls. However, as shown in this study girls are less likely to participate in making than boys are. This thesis proposes that art therapy and making-based therapy be offered or prescribed as options to attract both females and males[34] and therefore facilitate more equal access to therapeutic practices. Misan

[34] The author of this thesis recognises the problematic nature of making generalisation about what engages men and women and therefore advocates that both

and Sergeant (2008) anecdotally describe the benefits that they have observed in providing men with a place to go to make things. This further supports the notion that making-based therapy would work in the same way that art therapy does.

Positioning 3D printing pens as both a valuable maker tool and a tool for art-making, perhaps contradicts the discussion about the distinction between art, craft and making in section 6.2.6. Alternatively, 3D printing pens can be recognised as an art medium and a maker tool where both uses facilitate a sense of well-being. A tool which bridges the two disciplines would make makerspaces more conceptually accessible to artists, and art media in general could be positioned in the remit of a maker. This interdisciplinarity could be beneficial to both types of creators as it can expand material and process options.

Although this study observed that more boys attended the workshops, this study does not have the data to explain why making engages more boys than girls. Understanding the reason for this would require further studies, which is beyond the scope of this research. However, Wikberg (2013) describes art as ‘a subject that is often described with feminine connotations.’ She cites statistics provided by the Swedish National Agency for Education (2006:7). These show that participation in art is the biggest difference between subject uptake between boys and girls out of all school subjects. Studies by Lindström et al. (2009) show that girls spend more of their leisure time practicing painting while boys use technology more than girls (Marner et al. 2005). This further supports the position of 3D printing pens as a bridge between art and making, as boys, who have been recorded as less likely to participate in art in education (Etherington, 2008), participated in 3D printing workshops based on the use of 3D printing pens more frequently than girls.

7.7.5 Concluding thoughts

To conclude, this section has shown that researchers and public engagement curators value 3D printing pens less than 3D printers. Although Deans et al. (2016), Gogoi and Jeyapoovan (2016) and Imari et al. (2017) suggest that they can be valuable

types of therapies be available to all genders to ensure everyone can access the therapy best suited to their individual requirements and desires.

tools. However, this thesis argues that 3D printing pens are as valuable to maker-education as any other maker-tool included in a makerspace. The qualitative and empirical data shows that behaviours exhibited while using 3D printing pens match those of behaviours expected and exhibited in maker-spaces. Additionally, this section positioned 3D printing pens as a bridge between art practice and makers which is considered mutually beneficial to each field. Additionally, this thesis contributes a new perspective on art therapy, proposing that maker-based therapy should be offered as a way to improve equality of access to therapies. Finally, the greater number of male participants in stage 1 of this research show that 3D printing pens could be used as a way of engaging boys in school-based art education so that they can also experience the benefits associated with art-making in school.

7.8 Grounded theories

7.8.1 Making theory

Redström (2017:35) argues that design research should not be treated in the same way as scientific research with regards to its universal and particular qualities. He says that design research must be more nuanced to be relevant in alternative contexts, which is something that he says is not usually considered appropriate for a theory (Ibid, 2017:141). This perspective supports the development of theories grounded within data, as these are responding to the context of the data itself. Additionally, to generate grounded theories it is necessary to collect vast amounts of data which allows the findings to be extrapolated to other situations and contexts, while maintaining the rigour expected of traditional research. Redström (2017) sets out a method for making theory. This is: define the propositions from research findings, make these definitions unstable and transitional before developing composite definitions to provide a conceptual structure which other data can be placed on for testing (2017: 134-135). Considering this, theories were developed from the propositions of this study using the method outlined above.

7.8.2 Theories

(i) Benefits associated with a particular activity can be made available to anyone. By identifying existing participants' motivation to engage, these motivations can then be used to promote engagement in the activity. The potential benefits, specific to each activity, would thus become available to a wider range of participants.

(ii) User experience of a technology should be considered in context: facilitators should be aware of potential difficulties.

(iii) Exposure to social and physical risk aids the acquisition of evaluation and critical thinking skills.

(iv) There are valuable developmental potentials even in "tools" that are perceived to be of a trivial quality.

(v) Changing needs can be met with alternative approaches.

The basis of the above theories can be found in sections 7.3, 7.6, 7.5, 7.7 and 7.4 respectively.

7.9 Conclusion

This chapter has provided an overview of where the data presented in this thesis can sit alongside or contradict the data of previous studies. Five theories grounded within the data were then presented based on the five distinct findings of this study.

Firstly, an alternative perspective to the pursuit of making was provided. This proposes that access to making for leisure is undemocratic due to the necessity to have prior knowledge or an awareness of the distinction between making for leisure and making for necessity. This section advocated the consideration and exploration of the motivations for participation in different types of making. Further, it suggests that whilst making may be done by anyone, access and inclination cannot be assumed. Additionally, this section proposed that motivation to participate in making for leisure with no prior experience or knowledge of this type of making was social-based or learning-based. Inexperienced makers could participate in making for leisure as an antidote to social isolations or simply because their acquaintances were taking part. Alternatively, inexperienced makers may be motivated to make by curiosity and the desire to learn a defined skill.

Secondly, this chapter showed that engagement in 3D printing workshops help to develop a number of skills considered essential for learners in the 21st Century. Additionally, the data based on teacher perceptions provided by Trust and Malloy (2017) was substantiated by the empirical data from this study.

Thirdly, the importance of risk awareness and autonomy supportive environments were discussed before explaining how maker-based learning provides children with opportunities to explore risk and to challenge rules in a controlled and supervised environment.

This chapter then provided an overview of expectations held about 3D printing in education and the assertion that 3D printing is limited in what it can offer in a classroom environment. This thesis argues that the research conducted in this area is negatively influenced by teacher inexperience and shows examples from the data where an experienced 3D printing workshop facilitator was able to overcome the problems expressed. However, this does suggest that better resources must be made available to enable better implementation in future. A sample 12-week lesson plan was produced from the data collected to provide an outline to how 3D printing can be successfully introduced in a classroom environment.

Then, this chapter advocated the 3D printing pen as a tool of equal importance to 3D printers within a classroom environment. There is some evidence within academic literature which suggests that 3D printing pens are complementary to 3D printers. However, this thesis argues that they are excellent stand-alone tools which offer a low-cost route into maker-education, affording students with the associated benefits of engaging in the making process. A link between art and making through 3D printing pens was highlighted to suggest that 3D printing pens can be used for general making as well as art-making. By citing gender participation figures it was shown that making-based therapy offered alongside art therapy could improve the equity of access to therapeutic practices.

Finally, this chapter discussed Redström's (2017) method of theory building to provide a guide for transforming the propositions grounded within the data of this thesis into transitional theories, adaptable to different contexts. These theories were presented in section 7.8.2. The contribution this thesis makes can be found in section 7.2.

Chapter 8

8.1 Overview

This chapter will provide images to illustrate the research carried out in this study. Image collection was not used as a research method, but photographs were often taken throughout the workshops. These have been included to provide visual context for some of the descriptions within this thesis.

The images have been organised chronologically in relation to the structure of this thesis.

8.2 Workshops conducted for this research.

Figure 4 Youth Clubs

Figure 5 Regular 3D printing clubs

Figure 6 3D printing birthday parties

Figure 7 3D printing at holiday workshops

Figure 8 3D printing at faires

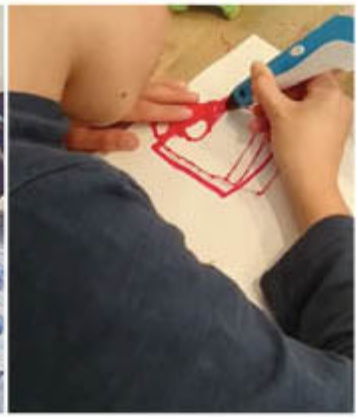

Figure 9 Private sessions

8.3 Types of workshops

Figure 10 Type A 3D printing club attended by unrelated children

Figure 11 Type B 3D printing club attended by a group of friends

Figure 12 Type C 3D printing club at a private school

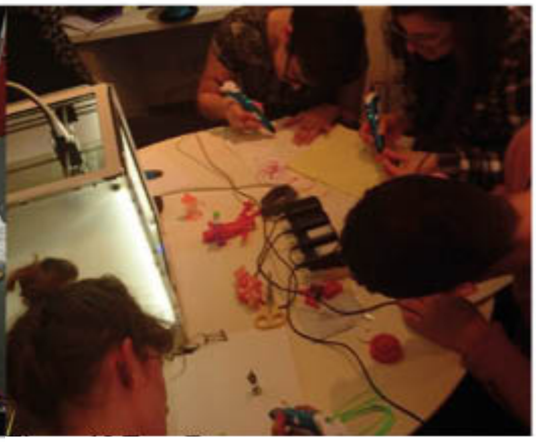

Figure 13 Type D 3D printing at an existing youth club

8.4 Categories taken forward

The 71 potential categories as described in Chapter 4 were condensed into 16 categories to take forward for further analysis. These are illustrated in the photographs below.

Figure 14 Engaged in problem solving

Figure 15 Engaged in social learning

Figure 16 Experienced enjoyment and fulfilment

Figure 17 Interdisciplinarity of technologies

Figure 18 Proud of achievement

Figure 19 Opportunity to communicate with peers about themselves

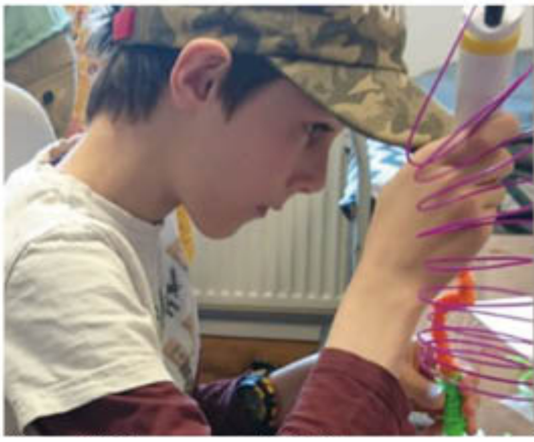

Figure 20 Engages a child's focus

Figure 21 Experience of agency

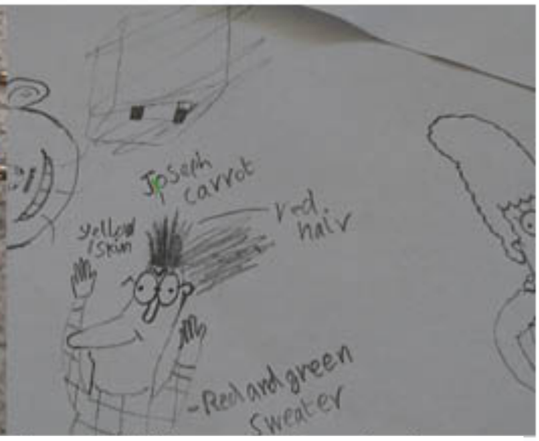

Figure 22 Experience of personal capacity

Figure 23 Evidence of project planning

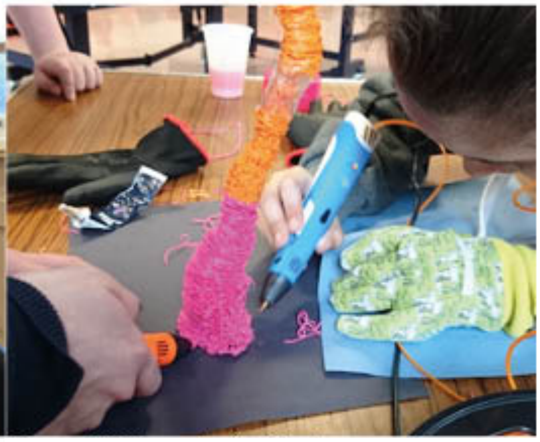

Figure 24 Satisfied with outcome of workshop

Figure 25 Opportunity for teamwork

Figure 26 Interest in production of weapons

Figure 27 Freer communication when making

Figure 28 Experience of amazement

Figure 29 Provision of guide increases engagement

8.5 Operation of 3D printing pen

The operation of a 3D printing pen has been demonstrated in the photographs below.

Figure 30 Operation of 3D printing pen- button

Figure 31 Plastic filament being loaded into 3D printing pen

Figure 32 Plastic extrusion

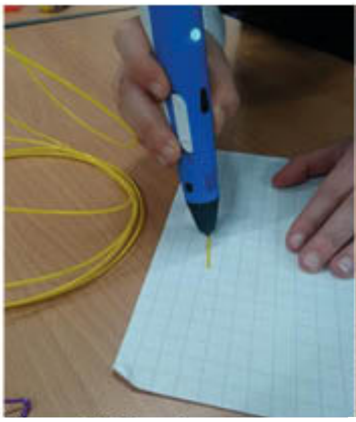

Figure 33 Drawing on paper with 3D printing pen

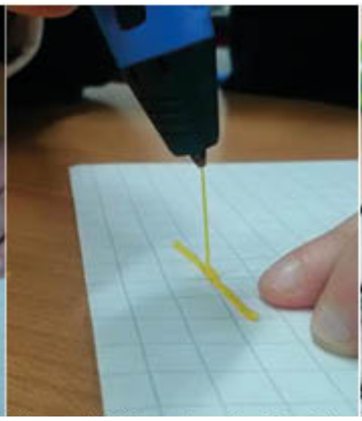

Figure 34 Drawing in air with 3D printing pen

Figure 35 Example of creation made with 3D printing pen

8.6 Defined behaviours

The six defined behaviours taken forward to test in the verification research were problem solving, social learning, expression of pride in achievement, opportunity to communicate with peers about themselves, experience of agency and satisfaction with outcome.

Illustration of problem solving behaviours:

Figure 36 Iterative design process to improve model

Figure 37 Talking through design problems with peers

Figure 38 Testing strength of model

Figure 39 Evidence of perseverance

Illustration of social learning behaviours:

Figure 40 Social learning through testing of learned engineering concepts

Figure 41 Learning from peers

Figure 42 Colosseum- creation made in relation to topic being studied at school

Illustration of expression of pride in achievement:

Figure 43 A participant showing off his shield

Figure 44 Participant happy with his solar system inspired Easter bonnet

Figure 45 Participant wearing his creation

Figure 46 Participant holding up his model to show the group

Figure 47 Participant showing off his model

Figure 48 Participant holding up his emoji

Illustration of opportunity to talk to peers about themselves:

Figure 49 Children talking about a game they play

Figure 50 Children talking about a YouTuber they like

Figure 51 Participants talking about Pokémon

Illustration of experience of agency:

Figure 52 Get Well Soon Gift made by participants

Figure 53 Participant pleased that she made something ‘real’ that moves

Figure 54 Participant made prank lens for his glasses to make his Mum think he had broken them

Figure 55 Composite image showing participant’s happiness that he had made a Pokéball home for his toy Pokémon

Figure 56 Participant happy with ‘real’ bracelet that she made

Illustration of satisfaction with outcome:

Figure 57 Child happy with outcome of workshop

Figure 58 Child happy at end of workshop

Figure 59 Child happy with his creation

Figure 60 Child happy with tower he made

Figure 61 Child happy with his Pokémon model

Figure 62 Child pleased with his model

8.7 Images associated with theoretical propositions

Theoretical proposition from data: motivation to make for leisure is impacted by desire to learn a particular skill or by wanting to socialise with friends.

Figure 63 Child attends due to desire to learn about 3D printers

Figure 64 Children motivated to attend in order to spend time with friends

Theoretical proposition from data: 3D printing pens are useful and important tools which provide access to a maker mindset.

Figure 65 Model made with 3D printing pen created in 10 minutes

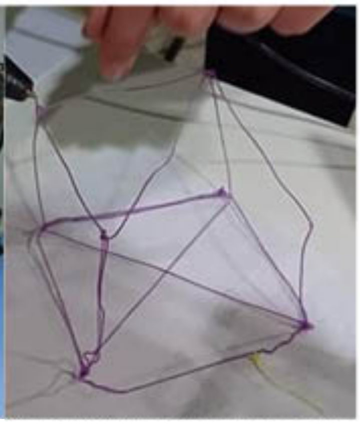

Figure 66 3D printing pen creating a wireframe

Theoretical proposition from data: Making provides opportunities for children to develop risk tolerance and to challenge rules in a safe and supportive environment.

Figure 67 Participant making ring by winding extruded filament around gloved finger

Figure 68 Ring created using method devised by individual participants

Theoretical proposition from data: impediments to 3D printing in a classroom environment can be overcome with experience and anticipation of potential problems.

Figure 69 3D printing pen model of a helicopter demonstrating flexibility of 3D printing pens to quickly create models of individual interest

Figure 70 Templates can be used to increase engagement and encourage perseverance

Figure 71 Evidence of a child's delight at the end of a workshop demonstrating that expectations of technologies can be managed to produce positive results

Conclusion

9.1. Overview

This chapter will provide a summary of why and how the research for this study was conducted before explaining what this thesis proposes in terms of findings. Finally, this chapter will finish with a short section of suggestions for further research based on the data already collected through this study.

9.2 Why this research was conducted

This study was inspired by experiences and anecdotal observations by the author through the 3D printing workshops she delivers as part of her business. The following quotation from 'diary entry 22' gives an example of an observation which compelled the author to find out more.

> 'Today he had a big pile of plastic lines next to him and when I asked him what it was he said it was his first 13 failures of the afternoon. He said it without any hint of frustration or disappointment. I asked him how he was getting on with it now and he said that he thought it was working now but he might start again if it did not work the way he wanted it to.' (appendix: 3, diary entry 22)

The author wanted to find out why when making with digital tools, children showed signs of significant perseverance, self-belief and confidence.

9.3 How this research was conducted

This study used a Grounded Theory methodology in order to generate new ideas and propositions from the data. An open approach to data collection was adopted. There was no hypothesis or set of guidelines regarding what to look for or to be aware of within the delivered workshops. The author was the researcher-facilitator and delivered 207 workshops for observation within the first phase of data collection and a further 40 workshops in the second phase of data collection.

9.3.1 Phase 1- Data collection

The researcher-facilitator delivered workshops for observation at regular 3D printing clubs, private classes, birthday parties, youth clubs, holiday clubs and faires. For each workshop delivered, a diary entry was made which noted the following: number of participants, gender, age-range, how participants accessed workshops, activity options and length of interaction. Diary entries were made as soon as possible after each workshop using field notes taken during the workshops.

9.3.2 Phase 1- Data reduction and coding

Due to the number of workshops delivered it was unfeasible to analyse each workshop to the depth desired as this would fall outwith the scope of a PhD. Therefore, the data was reduced to four workshop group types. It was decided to allocate each type of workshop with a label to make these differences identifiable and then comparable. These were: Type A for regular 3D printing clubs attended by an unrelated group of children who attended to learn how to use 3D printing technologies, Type B for regular 3D printing clubs attended primarily by one group of friends who wanted to spend time together, Type C for regular 3D printing clubs delivered as part of the extra-curricular education programme at a private school in Edinburgh and Type D for 3D printing workshops delivered at existing youth clubs which were attended by children and young people who went to spend time with friends and be provided with a meal.

The diary entries which correspond to the workshops described above were coded using open ended, line-by-line coding which resulted in 71 relevant events being identified. These were then condensed into fewer categories, which grouped similar relevant events together under a common 'potential category'. The resulting 16 categories were then used to re-code the data to ensure that all potential information was taken from the data. After this, the 16 categories were then narrowed down to 6 behaviours (categories) by discarding categories which were not considered to have occurred frequently enough to be taken forward. The 6 categories were: problem solving, social learning, expression of pride, opportunity to talk to peers about themselves, experience of agency and satisfaction with outcome.

9.3.3 Phase 2- Verification study design and data collection

Using the 6 categories defined in phase 1 of this research, a verification study was designed. The verification study was conducted by using a tally-checklist which allowed for the 6 categories to be searched for within additional workshops. When a particular behaviour or category was observed in a workshop, it was marked and the number of participants who exhibited this behaviour was noted.

A further 40 workshops were observed for the verification study. This study consisted of 10 of each type of workshop types A, B C and D. The information from these workshops provided data which could then be statistically analysed to give an indication of whether the differences between workshop types were statistically significant.

9.3.4 Phase 2- Analysis

An unpaired 2 tailed Student's t-test was conducted on the findings of the verification research. This allowed the types of workshops to be compared against each other to show what behaviours occurred, where they occurred and if this was more or less often than the other types of workshop. This provided empirical data which could support the findings of phase 1 qualitative research and that of claims made in existing literature which lack empirical evidence (Chu et al., 2015; Song, 2018). It is valuable to understand behaviour differences between the workshop types to evaluate the experiences and benefits of making in different environments.

9.3.5 Phase 1 and Phase 2 findings

Based on the observations and statistical analysis, the following findings were positioned as 'soft' theories:

1. Children with access to maker tools engage in problem solving which instils positive attitudes toward failure, provides more conducive environments for deep learning, understand risk and autonomy and become engaged in learning to make things well.

2. Informal maker learning environments provide a space where children can learn from the success of their peers; find the motivation to ask for help; offers the opportunity to develop deep understanding through exploration of concepts in the physical world; and offers flexibility for children to learn from a plurality of approaches.

3. Children value being able to do something entirely by themselves and making provides the opportunity to make something 'real' with little or no assistance from adults. This leads to recognition of their own hard work and in turn increases confidence.

4. Making provides children with a physical prompt which they can speak about and relate to their own personal stories about their own lives which they may desire to share with those around them.
5. A self-made artefact allows children to witness their own power in a tangible way and understand their place within their immediate environment.
6. Making gives children the potential for power and multiple applications for their endeavours; they are not constrained by the material as is typical within traditional children's art making.

9.3.6 Findings in context

The findings and 'soft' theories presented after the final stage of analysis were then situated within context. A review of literature was conducted and covered fields of research including, 'art, craft and making', 'The Maker Movement', 'Making and learning', '21st century skills' and 'Trust, respect, power and responsibility'. This provided an awareness of the research and findings of others which the data of this study could be related to, built upon or challenged. After contextualising the data, the main findings presented by this thesis are described below.

Making is driven by two key motivations for participation in making for leisure. These are to learn a new skill or to socialise with like-minded people. This clarification provides a means to promote making for leisure to those inexperienced in this type of making. The literature discusses making as something which everyone has access to (Hatch, 2014: 1). However, this thesis suggests that it is necessary to recognise making on a spectrum between making for necessity and making for leisure to ensure that claims made about benefits associated with making are not applied to all making without the data to support this. Additionally, the analysis of data collected in this study suggests that children attend 3D printing workshops for the key motivations outlined above. Therefore, by understanding the motivations of people who make for leisure these can be used as a way to promote the activity of making for leisure for those inexperienced in this type of making.

3D printing pens offer a low-cost access point to a maker mindset. This study demonstrates an extensive use of 3D printing pens and positions them as of equal importance to 3D printers within education settings. 3D printing pens are generally described as additional to 3D printers within the academic literature (Hancock, 2015, Nemorin, 2016). However, as shown in the diary entries recorded in this study, 3D printing pens were more commonly used by participants than 3D printers. This was explained by the tangible outcome of using these tools and providing participants with the means of producing something quickly that they could take home. Additionally, it was noted that children did not mind the aesthetic of a 3D printing pen model even though it looks more home-made (See figure 35).

It was shown that 3D printing can be successfully implemented into school settings. Through diary entries this thesis shows how limitations of 3D printers can be overcome. This can be achieved by using 3D printing pens for prototyping, provision of templates to engage makers in creating something they are interested in and encouraging an explorative approach to learning CAD. This contrasts with the suggestions of another study which cites 3D printers as being limited in what they can offer in a classroom setting (Nemorin, 2016).

Making can provide an autonomous supportive environment. Through the observations of children challenging rules and boundaries this thesis argues that educators and facilitators must take responsibility for supporting children and young people as they develop autonomy. The importance of this is highlighted by Van Der Kaap-Deeder et. al. (2016) who argue that children cannot be autonomous due to their stage of development and therefore must be supported through their power transition.

3D printing education can develop 21st Century Skills. The skills developed through the 3D printing workshops in this study can be matched to those considered necessary by the 'Harvard Advanced Leadership Initiative' (2014). The 3D printing workshops delivered in this study were shown to contribute to the development of both digital literacies and creative skills, which Reimer et al., (in Ibid) say are important so that 21st Century learners can be flexible and adaptable in the way they use and approach advancing technologies.

9.3.7 Transitional theories

Using the theory making method as directed by Redström (2017), the following theories were made from the theories grounded within the data of this thesis.

(i) Benefits associated with a particular activity can be made available to anyone. By identifying existing participants' motivation to engage, these motivations can then be used to promote engagement in the activity. The potential benefits, specific to each activity, would thus become available to a wider range of participants.

(ii) User experience of a technology should be considered in context: facilitators should be aware of potential difficulties.

(iii) Exposure to social and physical risk aids the acquisition of evaluation and critical thinking skills.

(iv) There are valuable developmental potentials even in "tools" that are perceived to be of a trivial quality.

(v) Changing needs can be met with alternative approaches.

9.4 Contributions

As detailed in the contribution statement in section 7.2, this thesis makes several contributions in terms of data collected and presented within the appendix as well as the theoretical propositions and transitional theories proposed through the analysis and contextualisation of this collected data. These are:

(I) 3D printing as an activity has an intrinsic pedagogical property that has a positive impact derived from the experience of engaging in the activity itself.

(II) **The motivation to access making for leisure can be conceptualised as social or learning based. This contributes to the discussion on accessibility of maker-spaces and maker communities**

(III) **A lesson plan which acts as a step to developing a consensus on how a pedagogy of 3D printing may be developed and achieved.**

(IV) **A new perspective on autonomy-supportive development through making.**

9.5 Reflections on Grounded Theory as a methodology

The researcher considered Grounded Theory as a suitable and fruitful methodology for this study. She sought to learn more about children and their experience of making while also challenging her own bias from personal experience, which this methodology facilitates through vast data sets and analysis to saturation (Glaser, 2002: 3). Choosing Grounded Theory as the methodology allowed her to collect a large amount of data before narrowing the focus which meant that the data was necessarily instrumental in directing how the research would progress. Research regarding children and making is relatively new and as such there is not a large corpus of pre-existing research. Grounded Theory, as a methodology seeks to collect a large amount of data for analysis, which made it particularly appropriate in this context. As this field of research is young it felt pertinent to search within the data itself for direction rather than looking to other fields, theories and frameworks to see where these could apply to children and making.

However, the strengths described above can also be reframed as the methodologys greatest weaknesses. Findings of this type of research lack a specificity associated with traditional research, that is to say that traditional research normally looks for a particular characteristic or phenomenon, whereas grounded theory looks more broadly at the phenomena. Commitment to theoretical sensitivity (see chapter 2 for further discussion on this) is essential to ensure that the interpretation and analysis of data is as unbiased as possible. Additionally, a vast data-set is necessary so that observed consistencies can be verified and meaning can be established. This poses practical considerations in reference to length of study and access to adequately extensive subject groups for analysis. This means that any potential Grounded Theory study needs to be large scale in order to be rigorous. This may limit its potential to be used in particular contexts. An additional potential issue with this methodology is as Gasson (2009) observes is that it is particularly vulnerable to being misapplied in order to support and curate desirable findings and so to flatter cognitive or even political biases. This however, is a vulnerability relevant only to a conscious misapplication or selective use of Grounded Theory: if correctly and honestly applied it can offer new insights and challenge accepted truths, as well as the patriarchical hierarchies often present in a traditional research methodologies.

Due to the anxieties noted above, Grounded Theory has at times been seen as a controversial research methodology (Mjøset, 2005)[35]. There are many conflicting interpretations of it and debates amongst its biggest advocates populate the literature (Glaser, 2004; Howard-Payne, 2016). A rigorous application and commitment to honesty in both application and analysis of this type of research is essential for its success and for the reputation of the research.

Grounded Theory is particularly useful when conducting research in a new area or when researching a new phenomenon as it allows the researcher to develop novel theory (Timmermans & Tavory, 2012) as discussed above. Using another methodology such as ethnography (Harrison, 2018) or phenomenology (Henriksson, 2012) would have presented alternative insights and knowledge into the use of 3D printing activities in education and contributed to the knowledge in a different way than Grounded Theory did in this study. However, it was felt that by using any other methodology to research a new area or phenomenon would inevitably mean that the

[35] Mjøset (2005) presents debates around approaches to Grounded Theory and the impact that misapplications have had on its reputation. They draw the conclusion that, Grouded theory, ‘deserves to be treated as an approach that survives a systematic assessment in line with contemporary philosophy and sociology of scientific knowledge.’(2005:407)

research was being conducted through the lens of another discipline, phenomenon, theory or framework which would necessarily mean that the researcher had explicit preconceived notions or ideas that did not come from the data itself (Charmaz, 2014).

The field of children and making research has only developed over the last decade and therefore as yet, it lacks a wide range of literature and studies. Additionally, the author of this thesis was in the unique position to conduct a large number of workshops and whilst another researcher without these means may have been limited to another methodology, Grounded Theory was considered to be the most appropriate method in the circumstances. The researcher felt that she could commit to the rigour and honesty necessary for the successful application of Grounded Theory.

9.6 Limitations of study

Limitations of this study will be described below so that the findings and data may be considered within the context of these limitations.

- The research of phase 1 which provides the foundation for the study relies on diary entries from observations which were noted when possible during and after workshops. Where there was a delay in recording observations it is possible that reflection could have influenced the relevant diary entry. However, this was consciously avoided as much as possible.

- Due to the large number of workshops and unpredictable settings it is possible that observations were influenced by a particularly positive or negative event at a workshop. For example, some workshops which were not organised by the researcher-facilitator were in settings that could be violent and chaotic which made working conditions difficult. It can therefore be difficult to maintain consistency in the quality and recording of the workshop.

- The progress of the study was directed by the data alone which meant that things that were not noted consistently in diary entries did not get analysed or tested in phase 2 of the research. However, the researcher is aware that some observations were more common than the diary entries suggest[36]. However, this does not affect the findings or analysis of what was observed but it does highlight that there may be more that could be discovered using a more traditional approach to data collection.

- Subjectivity and objectivity was wrestled with in phase 2 of this study. An explanation and interpretation of this was provided in chapter 3, which positions the data as hybrid subjective-objective data. However, debates around subjectivity and objectivity are extensive and as such the categorisation of phase 2 data being hybrid may be challenged by those who believe that data must be subjective or objective (Kuhn, 1977).

- Additionally, the application of statistics on this type of data could be scrutinised due to the subjective foundation of the dataset. However, it was highlighted that statistical analysis was used to indicate significant differences between workshop types and thus was not instrumental in developing the core or central argument of the thesis which was instead drawn from the application of Grounded Theory to the principle data.

9.7 Further research

The vast amount of quantitative and qualitative data collected in this study meant that a minority of it was used. Whilst there were many interesting observations, only those observed most often were taken forward for verification, analysis and contextualisation for this thesis. The remaining data suggests that there may be many more interesting discoveries to be made.

[36] For example, paper templates or guides for 3D printing pens have been used by almost every person the researcher has ever worked. However, this is not something that appeared frequently within the diary entries and therefore it wasn't taken forward for analysis.

This thesis considers happiness of child at end of workshop and satisfaction with the outcome of their project. However, a deeper sense of fulfilment and transformation of children was observed on a number of occasions. Whilst, this was not observed often enough to warrant further analysis as part of this study, it would be interesting to explore further. It may link with another observation that 3D printing workshops facilitate the experience of personal capacity. Empowering children to direct their own learning processes, with support from an experienced teacher or facilitator would be particularly interesting to investigate in the context of flipped classrooms.

Relatedly, the diversity of backgrounds of children attending the workshops was matched by a vast range of confidence, levels of creativity and focus. This thesis has touched on these behaviours from the perspective of motivations for attending. However, deeper analysis of these traits and observations may reveal further implications of making. The observation of children opting to mix digital making methods reflect the interdisciplinarity of digital technologies. However, it may also represent opportunities to engage children with a variety of strengths and interests and promote organic opportunities for teamwork.

An unexpected observation in many of the delivered workshops was the interest in making weapons using 3D printing technologies. This may be related to the media popularising this notion or because weapons are often explored through children's play (Cheng et al., 2003). A follow-up study of this particular observation may benefit from contextualising these observations within research into child exposure to weapons through other media, e.g., games (Ybarra et al., 2014).

The provision of templates and guides within workshops were shown to be related to an increase in focus of participants. Additionally, many children came to workshops with a pre-prepared plan for what they wanted to achieve. This may be interesting to research within the context of relatedness to a child's interests and the structure of their environment and activities. Additionally, this could be considered within a more focused study on 21st Century skills and how children demonstrate them.

Finally, the diary entries implied that children were more likely to communicate with others when they were in the process of making. However, this was discarded after stage 1 of this research due to this observation being recorded in relatively few workshops. This could be an interesting behaviour to research to inform an understanding of overcoming shyness in children, under a wider umbrella of art-therapy.

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3D printing education as a means of building confidence and preparing children for skills considered necessary for the 21st Century. A grounded theory study verified by empirical research.

Volume 2

Denise Elizabeth Milne

A thesis submitted in partial fulfilment of the requirements of Edinburgh Napier University for the award of Doctor of Philosophy.

July 2020

Appendix 1- Consent form

Edinburgh Napier University Research Consent Form
The investigation of natural interactions between children and digital making technologies

Edinburgh Napier University requires that all persons who participate in research studies give their written consent to do so. Please read the following and sign it if you agree with what it says.

1. I freely and voluntarily consent to my child being a participant in the research project on the topic of natural interactions with technology to be conducted by Denise Allan, who is a postgraduate student at Edinburgh Napier University.
2. The broad goal of this research study is to explore how children naturally interact with digital making technology and what they want to make or what they think is possible.
3. I have been told that my child's responses will be anonymised. His/Her name will not be linked with the research materials, and he/she will not be identified or identifiable in any report subsequently produced by the researcher.
4. I also understand that if at any time during the session my child feels unable or unwilling to continue, he/she is free to leave. That is, my child's participation in this study is completely voluntary, and he/she may withdraw from it without negative consequences. However, after data has been anonymised or after publication of results it will not be possible for my child's data to be removed as it would be untraceable at this point.
5. In addition, should my child not wish to answer any particular question or questions, he/she is free to decline.
6. I have been given the opportunity to ask questions regarding the session and my questions have been answered to my satisfaction.
7. I have read and understand the above and consent to my child's participation in this study. My signature is not a waiver of any legal rights. Furthermore, I understand that I will be able to keep a copy of the informed consent form for my records.

Participant's Parent's Signature Date

I have explained and defined in detail the research procedure in which the respondent has consented to participate. Furthermore, I will retain one copy of the informed consent form for my records.

Researcher's Signature Date

I consent to my child being photographed/videoed for the purposes of this research.
Photographed: Yes No (please circle as appropriate)
Videoed: Yes No (please circle as appropriate)

I do not want my child to participate in the research at all. Child's name:

Appendix 2- Stage 1 research- initial data-collection

Corrsponding diary entries	Workshop label	No of Boys	No of Girls	Objective	Paid per person (PPP) or by organisation (O)	Optional activity (N/Y)	Reason for workshop	Time/Interaction	Length of Workshop	Age range
	a	5	10	Party	O	Yes	Party	15-20 mins	3hrs	7-11years
	b	19	31	Faire	O	Yes	School faire	10 mins	3hrs	6-10years
	c	1	7	Introduction to 3D printing	PPP	No	Community workshop	2hrs	2hrs	5-11years
1	d	2	0	3D printing club	PPP	No	Club	1hr	1hr	8years
2	e	4	4	3D printing club	PPP	No	Club	1hr	1hr	5-15 years
3	f	5	2	3D printing club	PPP	No	Club	1hr	1hr	5-13years
4	g	2	4	3D printing club	PPP	No	Club	1hr	1hr	5-13years
5	h	2	3	3D printing club	PPP	No	Club	1hr	1hr	9-13years
	i	3	6	party	O	No	Party	2hrs	2hrs	7-9years
6	j	4	1	3D printing club	PPP	No	club	1hr	1hr	6-15years
7	k	4	1	3D printing club	PPP	No	Club	1hr	1hr	5-13years
8	l	4	2	3D printing club	PPP	No	Club	1hr	1hr	5-13years
	m	14	8	Introduction to 3D printing- yo	O	Yes	Youth Club	1.5hrs	1.5hrs	11-18years
9	n	8	0	3D printing club	O	Yes	Club	1hr	1hr	11-18years
10	o	5	0	3D printing club	PPP	No	Club	1hr	1hr	5-9years
11	p	9	0	3D printing club	PPP	No	Club	1hr	1hr	11-12years
12	q	5	0	3D printing club	PPP	No	Club	1hr	1hr	5-9years
	r	5	0	Private workshop	PPP	No	Private party request	2hrs	2hrs	15-16years
13	s	8	0	3D printing club	PPP	No	Club	1hr	1hr	11-12years
14	t	5	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
15	u	7	0	3D printing club	PPP	No	Club	1hr	1hr	11-12years
16	v	5	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
17	w	8	0	3D printing club	PPP	No	Club	1hr	1hr	11-12years
18	x	6	0	3D printing club	PPP	No	Club	1hr	1hr	3-10years
19	y	8	0	3D printing club	PPP	No	Club	1hr	1hr	11-12years
20	z	10	0	3D printing club	PPP	No	Club	1hr	1hr	5-9years
	a1	1	0	Private session- project work	PPP	No	Private session	1hr	1hr	6years
21	b1	8	1	3D printing club	PPP	No	Club	1hr	1hr	9-12years
22	c1	12	0	3D printing club	PPP	No	Club	1hr	1hr	5-11years
23	d1	9	1	3D printing club	PPP	No	Club	1hr	1hr	9-12years
	e1	7	10	Holiday workshop	PPP	No	Holiday programme	2hrs	2hrs	7-14years
24	f1	2	1	3D printing club	PPP	No	Club	1hr	1hr	8-11years
25	g1	9	0	3D printing club	PPP	No	Club	1hr	1hr	8-11years
	h1	108	72	Maker Faire	O	Yes	Faire	10 mins	6hrs	3-50years
26	i1	8	0	3D printing club	PPP	No	Club	1hr	1hr	11-12years
27	j1	11	0	3D printing club	PPP	No	Club	1hr	1hr	5-12years
	k1	3	4	80th birthday party	O	No	Party	2hrs	2hrs	30-80years
	l1	5	2	Birthday party	O	No	Party	2hrs	2hrs	6-9years
	m1	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	9years
28	n1	0	2	3D printing club	PPP	No	Club	1hr	1hr	9-10years
29	o1	9	0	3D printing club	PPP	No	Club	1hr	1hr	2-9years
30	p1	5	2	3D printing club	PPP	No	Club	1hr	1hr	9-11years
31	q1	8	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
	r1	43	7	Faire	O	Yes	Faire	10 mins	4hrs	4-15years
	s1	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	9years
32	t1	3	2	3D printing club	PPP	No	Club	1hr	1hr	8-11years
33	u1	8	2	3D printing club	PPP	No	Club	1hr	1hr	6-11years
123	v1	8	14	Youth club	O	No	Youth club	1.5hrs	1hr	10-11years
124	w1	10	14	Youth club	O	Yes	Youth club	1hr	2hrs	9-14years
34	x1	4	2	3D printing club	PPP	No	Club	1hr	1hr	7-11years
35	y1	9	2	3D printing club	PPP	No	Club	1hr	1hr	6-11years
126	z1	16	14	Youth club	O	Yes	Youth Club	1hr	2hrs	7-9years
125	a2	10	14	Youth club	O	Yes	Youth Club	1hr	2hrs	9-12years
127	b2	2	4	Youth club	O	Yes	Youth Club	2hrs	2hrs	13-16years
128	c2	16	14	Youth club	O	Yes	Youth Club	1hr	2hrs	10-13years
36	d2	4	2	3D printing club	PPP	No	Club	1hr	1hr	7-11years
37	e2	9	2	3D printing club	PPP	No	Club	1hr	1hr	6-11years
129	f2	11	14	Youth club	O	Yes	Youth Club	1hr	2hrs	9-12years
	g2	4	3	Private workshop	O	No	Private session	1hr	3hrs	4-10years
38	h2	3	2	3D printing club	PPP	No	Club	1hr	1hr	7-11years
39	i2	9	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
	j2	2	3	Private session	O	Yes	Private session	1hr	1hr	70+ years
130	k2	10	20	Youth club	O	Yes	Youth Club	1hr	2hrs	9-15years
131	l2	3	10	Youth club	O	Yes	Youth Club	1hr	2hrs	15-18years
	m2	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	9years
132	n2	12	8	Youth club	O	Yes	Youth Club	1hr	2hrs	7-9years
40	o2	7	1	3D printing club	PPP	No	Club	1hr	1hr	9-11years
41	p2	7	1	3D printing club	PPP	No	Club	1hr	1hr	9-11years
	q2	4	14	Private workshop	O	No	Private session	2hrs	2hrs	3-18+ years
	r2	2	7	Faire	PPP	Yes	Faire	30mins	3hrs	4+ years
	s2	5	5	Private workshop	O	No	Private session	1hr	1hr	11-13years
42	t2	5	1	3D printing club	PPP	No	Club	1hr	1hr	9-11years
	u2	3	2	Private session	O	Yes	Private session	1hr	1hr	70+
43	v2	6	1	3D printing club	PPP	No	Club	1hr	1ht	6-11years
44	w2	9	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
	x2	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	9years
133	y2	21	19	Youth club	O	Yes	Youth Club	1hr	2hrs	7-9years
45	z2	4	1	3D printing club	PPP	No	Club	1hr	1hr	9-11years
46	a3	8	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
134	b3	18	22	Youth club	O	Yes	Youth Club	1hr	2hrs	10-13years
135	c3	12	18	Youth club	O	Yes	Youth Club	1hr	2hrs	6-12years
47	d3	9	1	3D printing club	PPP	Yes	Club	1hr	1hr	6-11years
	e3	4	16	Holiday workshop	O	Yes	Community workshop	1hr	2hrs	5-11years
	f3	9	11	Holiday workshop	O	Yes	Community workshop	1hr	2hrs	7-11years
	g3	1	1	Private session	O	Yes	Private session	1hr	1hr	70+
	h3	7	18	Holiday workshop	O	Yes	Community workshop	1hr	2hrs	6-12years
	i3	10	12	Holiday workshop	O	Yes	Community workshop	1hr	2hrs	6-12years
48	j3	2	8	3D printing club	PPP	No	Club	1hr	1hr	6-15years
	k3	10	8	Holiday workshop	O	Yes	Community workshop	1hr	2hrs	7-11years
49	l3	4	5	3D printing club	PPP	No	Club	1hr	1hr	6-10years
	m3	5	9	Holiday workshop	O	Yes	Community workshop	1hr	1hr	7-10years
	n3	11	10	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	o3	10	9	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	p3	17	8	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	q3	10	20	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	r3	6	15	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	s3	10	15	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	t3	8	12	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	u3	10	12	Holiday workshop	O	Yes	Holiday programme	1hr	1hr	6-10years
	v3	9	7	Holiday workshop	O	Yes	Holiday programme	1hr30mins	1hr	6-9years
	w3	14	12	Holiday workshop	O	Yes	Holiday programme	1hr30mins	1hr	7-14years
	x3	5	2	Holiday workshop	PPP	No	Holiday course	2hrs	2hrs	8-14years
	y3	14	11	Holiday workshop	O	Yes	Holiday programme	2hrs	45 mins	7-10years
	z3	5	2	Holiday workshop	PPP	No	Holiday course	2hrs	2hrs	8-14years
	a4	5	2	Holiday workshop	PPP	No	Holiday course	2hrs	2hrs	8-14years
	b4	14	12	Holiday workshop	O	No	Holiday programme	1hr30mins	45mins	6-11years
	c4	5	2	Holiday workshop	PPP	No	Holiday course	2hrs	2hrs	8-14years
50	d4	6	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
	e4	5	2	Holiday workshop	PPP	No	Holiday course	2hrs	2hrs	8-14years
	f4	2	8	Birthday party	O	No	Birthday party	2hrs	1hr45mins	7-9years
	g4	0	2	Private session- medical	O	No	Taster workshop	1hr	1hr	6-12years
	h4	1	0	Private session-medical	PPP	No	Private session	1hr	1hr	10years

	i4	22	14	Holiday workshop	O	No	Holiday programme	1hr	2hrs	9-15years
51	j4	7	1	3D printing club	PPP	No	Club	1hr	1hr	9-11years
52	k4	7	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
53	l4	8	0	3D printing club	PPP	No	Club	1hr	1hr	9-11years
54	m4	9	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
	n4	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	10years
55	o4	8	0	3D printing club	PPP	No	Club	1hr	1hr	9-12years
56	p4	7	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
	q4	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	10years
57	r4	6	2	3D printing club	PPP	No	Club	1hr	1hr	9-12years
58	s4	7	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
59	t4	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
60	u4	11	1	3D printing club	PPP	No	Club	1hr	1hr	8-13years
61	v4	6	0	3D printing club	PPP	No	Club	1hr	1hr	6-11years
62	w4	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
63	x4	7	1	3D printing club	PPP	No	Club	1hr	1hr	8-12years
64	y4	7	0	3D printing club	PPP	No	Club	1hr	1hr	6-11years
65	z4	8	1	3D printing club	PPP	No	Club	1hr	1hr	8-12years
66	a5	8	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
67	b5	7	0	3D printing club	PPP	No	Club	1hr	1hr	9-11years
68	c5	8	1	3D printing club	PPP	No	Club	1hr	1hr	6-11years
69	d5	6	1	3D printing club	PPP	No	Club	1hr	1hr	9-12years
70	e5	6	1	3D printing club	PPP	No	Club	1hr	1hr	6-12years
71	f5	5	5	3D printing club	PPP	No	Club	45mins	45 mins	6-7years
72	g5	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
73	h5	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
74	i5	7	0	3D printing club	PPP	No	Club	1hr	1hr	9-12years
75	j5	9	1	3D printing club	PPP	No	Club	1hr	1hr	4-12years
76	k5	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
77	l5	4	0	3D printing club	PPP	No	Club	1hr	1hr	10-11years
136	m5	0	14	Girls youth club	O	No	Community workshop	1hr30mins	1hr30mins	9-13years
78	n5	5	2	3D printing club	PPP	No	Club	1hr	1hr	6-10years
137	o5	12	4	Youth Club	O	Yes	Community workshop	1hr30mins	30mins	14-17years
79	p5	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
138	q5	24	6	Youth Club	O	Yes	Community workshop	1hr30mins	30mins	7-9years
80	r5	6	0	3D printing club	PPP	No	Club	1hr	1hr	9-12years
139	s5	0	11	Girls youth club	O	Yes	Community workshop	1hr30mins	45mins	10-17years
81	t5	7	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
140	u5	14	10	Youth Club	O	Yes	Community workshop	1hr30mins	30mins	9-12years
141	v5	8	3	Youth Club	O	Yes	Community workshop	2hrs	30mins	10-17years
142	w5	6	0	Youth Club	O	Yes	Community workshop	1hr30mins	30mins	14-17years
82	x5	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
83	y5	6	2	3D printing club	PPP	No	Club	1hr	1hr	8-12years
84	z5	6	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
85	a6	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
86	b6	4	2	3D printing club	PPP	No	Club	1hr	1hr	8-12years
87	c6	6	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
88	d6	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
89	e6	6	2	3D printing club	PPP	No	Club	1hr	1hr	8-12years
90	f6	8	2	3D printing club	PPP	No	Club	1hr	1hr	6-12years
91	g6	5	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
92	h6	6	2	3D printing club	PPP	No	Club	1hr	1hr	8-12years
93	i6	7	1	3D printing club	PPP	No	Club	1hr	1hr	6-12years
94	j6	4	5	3D printing club	PPP	No	Club	45mins	45mins	6-7years
95	k6	7	1	3D printing club	PPP	No	Club	1hr	1hr	8-12years
96	l6	9	2	3D printing club	PPP	No	Club	1hr	1hr	6-12years
	m6	14	7	Christmas Faire	PPP	Yes	Community workshop	20mins	2hrs	5-16years
143	n6	34	23	Youth Club	O	Yes	Community workshop	30mins	2hrs	7-10years
97	o6	4	1	3D printing club	PPP	No	Club	1hr	1hr	8-11years
98	p6	4	1	3D printing club	PPP	No	Club	1hr	1hr	6-10years
99	q6	5	2	3D printing club	PPP	No	Club	1hr	1hr	8-12years
100	r6	5	1	3D printing club	PPP	No	Club	1hr	1hr	6-10years
	s6	1	0	Private session-medical	PPP	No	Private session	1hr	1hr	10years
101	t6	6	2	3D printing club	PPP	No	Club	1hr	1hr	8-12years
102	u6	7	1	3D printing club	PPP	No	Club	1hr	1hr	6-12years
144	v6	31	28	Youth Club	O	Yes	Community workshop	30mins	2hrs	11-15years
103	w6	5	7	3D printing club	PPP	No	Club	1hr	1hr	6-7years
104	x6	8	0	3D printing club	PPP	No	Club	1hr	1hr	9-11years
105	y6	6	1	3D printing club	PPP	No	Club	1hr	1hr	6-12years
145	z6	9	6	Youth Club	O	No	Community workshop	1hr30mins	1hr30mins	7-10years
106	a7	5	7	3D printing club	PPP	No	Club	1hr	1hr	6-7years
107	b7	7	0	3D printing club	PPP	No	Club	1hr	1hr	9-11years
108	c7	5	0	3D printing club	PPP	No	Club	1hr	1hr	6-10years
146	d7	10	9	Youth Club	O	No	Community workshop	1hr30mins	1hr30mins	7-10years
	e7	24	7	Holiday workshop	O	No	Community workshop	45mins	1hr30mins	6-11years
	f7	9	7	Holiday workshop	O	No	Community workshop	45mins	1hr30mins	7-10years
147	g7	9	8	Youth Club	O	No	Community workshop	1hr30mins	1hr30mins	7-10years
	h7	4	8	Art Club	PPP	No	Private club	2hrs	2hrs	7-15years
109	i7	5	7	3D printing club	PPP	No	Club	45mins	45mins	6-7years
110	j7	7	0	3D printing club	PPP	No	Club	1hr	1hr	9-11years
111	k7	6	0	3D printing club	PPP	No	Club	1hr	1hr	6-11years
148	l7	11	8	Youth Club	O	No	Community workshop	1hr30mins	1hr30mins	7-10years
	m7	3	7	party	O	No	Birthday party	2hrs	2hrs	9-10years
112	n7	5	7	3D printing club	PPP	No	Club	45mins	45 mins	6-7years
113	o7	6	1	3D printing club	PPP	No	Club	1hr	1hr	8-12years
114	p7	6	1	3D printing club	PPP	No	Club	1hr	1hr	6-12years
115	q7	5	7	3D printing club	PPP	No	Club	45mins	45mins	6-7years
116	r7	8	2	3D printing club	PPP	No	Club	1hr	1hr	6-12years
	s7	1	9	Unicorn party	O	No	Birthday party	1hr30mins	1hr30mins	9-10years
117	t7	5	7	3D printing club	PPP	No	Club	45mins	45 mins	6-7years
118	u7	7	1	3D printing club	PPP	No	Club	1hr	1hr	8-12years
119	v7	5	7	3D printing club	PPP	No	Club	45mins	45mins	6-7years
149	w7	5	7	Youth Club	O	No	Community workshop	1hr30mins	1hr30mins	7-10years
	x7	1	0	Private session- medical	PPP	No	Private session	1hr	1hr	10 years
120	y7	5	7	3D printing club	PPP	No	Club	45mins	45mins	6-7years
121	z7	7	2	3D printing club	PPP	No	Club	1hr	1hr	6-12years
122	a8	5	7	3D printing club	PPP	No	Club	45mins	45mins	6-7years
	b8	4	1	Special workshop	PPP	No	Community workshop	2hrs	2hrs	9-11years
	c8	7	9	Holiday workshop	O	No	Community workshop	45mins	1hr30mins	7-11years
	d8	14	12	Holiday workshop	O	Yes	Community workshop	30mins	1hr30mins	7-16years
	e8	91	72	MakerFaire	O	Yes	Faire	10mins	6hrs	5+ years

Appendix 3- Diary entries

Name	1
Boys	2
Girls	0
Type	3D printing club
Cost	PPP
Age	8

Description

This was the first class at Balerno. I hired the scout hall for 1hr and set it up so there was the 3D printer, laptops with Google SketchUp, 3x 3D printing pens and a variety of filament. To try to ensure I would be prepared I advertised the class through Facebook and flyers and posters displayed in the windows of local businesses and asked for people to book in advance. I had one email asking to book a place for 2 boys. On the day they arrived and took a seat.

I talked them through the different things and demonstrated how the 3D printer works. They each chose something that I already had prepared on the sd card. Once the printer was printing the boys took a 3D printing pen and started to draw with them.

One of the boys was not particularly interested in the 3D printing pens and said he was not arty, but he did go on to tell me that he designs models for selling through games online. He told me he uses a programme called 'Wings 3D'. While not particularly interested in making anything in particular using the pen he was very laid back and chatty about the different things he makes.

The other boy was really focussed on using the pen and made little monster type characters. He didn't speak very much but when he did speak about personal things, he seemed quite pessimistic. He asked about things he could make using the 3D printer, such as guns, hammers and if he could make traps to annoy his brothers.

The first boy tried Google SketchUp and said he would download it at home to practice for next week. This boy's Mum returned a little early to pick them up and so she joined in. She is a jeweller and loved seeing the 3D printer. She took a video. She also made a small sculpture of a cat. She said she thought that it would be good to have these in schools to make things a little more interesting and exciting.

Quotes/Questions:
"Can you print in more than one material or is it just plastic?"
"So, in future could we print circuit boards and have them fully enclosed in a plastic casing without need for assembly?"
"My dad is a programmer and he writes programmes that can be used to make models."
"Can we print something bigger?"
"What is the longest print you've ever done?"

Name	2
Boys	4
Girls	4
Type	3D printing club
Cost	PPP
Age	5-15

Description

This was the second class at Balerno. This time there were 4 boys, including the 2 from last week and 4 girls. The other two boys included a 10-year-old and a 5-year-old. The girls were teenagers from Balerno High School.

For the benefit of the new ones I demonstrated the 3D printer and showed them how the pens worked. Since there were so many who unexpectedly showed up, I didn't have enough pens for everyone to use so they used the pens and laptops in rotation.

One of the new boys sat almost in silence for the whole hour and worked away by himself. By the end of the session he had made a figure the size of his hand and was delighted with it. Though very shy he said he couldn't wait until next week.

The other new boy was extremely confident and chatty considering his age in a new environment. He was easily frustrated when the pens did not work the way he expected but was not put off by it either.

Three of the girls used the pens as though they were a craft tool, which of course they are but unlike the boys in the group they didn't express the obvious correlation between the pens and the printer. They seemed to really enjoy it, but it didn't seem to have the wowness that most children seem to feel when using them.

The boys who came the previous week were just as impressed and pleased. The more confident one of these two used the laptop to make a model of a house on SketchUp. He also used the iPad and tried out an app called tinker cad to make an articulated dinosaur.

The other girl used the laptop and was really focussed on making a shelter for her hamster.

Quotes/observation:
"So, I can make anything I want? Like a cage for my hamster?"
"Do we put our 3D printed drawings inside the printer?"
"If the plastic is the same material as Lego, can we make Lego?"
"I really like this."
"It's so cool. I'm going to ask Santa for one."

Name	3
Boys	5
Girls	2
Type	3D printing club
Cost	PPP
Age	5-13years

Description

This was the third class at Balerno. Unfortunately, I forgot to take the extension plugs with me, so the class was split up across the hall, which was not ideal. However, there were enough plug points and it ended up meaning that there were different tables for different activities which worked out fine. The 3D printer was at one table with 2 laptops. There was a table of table of 4 3D printing pens. A table with Pre-printed models which the kids could assemble. And there were also 3 iPad with Tinker Cad software.

There were two new children this week, a girl (aged 11) who was the older sister of one of the boys and another boy who was seven.

The girl was really interested in how she could take a 3D printed model and customise it using the 3D printing pens. She took one of the pre-printed horses and designed a little environment for it using the pens. She made a field with a fence. She also adapted the horse to give it a unicorn horn.

The new boy was very excited by both the 3D printer and the 3D printing pens. He enthusiastically used the pens but treated it more as a sculpting tool and so burnt his hand a few times by trying to manipulate the melted plastic with his hand. Note: Get gloves.

Another boy, who had designed a dinosaur on Tinker Cad the previous week sat for most of the hour building his dinosaur. He was delighted with it and all the other children were amazed by it and wanted to make one too. He offered advice to some of the other children and gave them tips about what he had learned.

The girl from last week who wanted to make a shelter for her hamster spent the whole session on Google SketchUp designing her shelter.

Quotes/observations:
"Oh wow. Can I do this for the rest of my life?"
"This is the coolest toy I've ever had."
"Can we try to make something really big that we all make a little bit of?"
"Please can you show me how you made that?"
"It's really hard. I'm rubbish at it but I'm going to keep trying."

Name	4
Boys	4
Girls	2
Type	3D printing club
Cost	PPP
Age	5-13

Description

This was a special Christmas session. Instead of having the normal relaxed, 'use whatever tools however you want' atmosphere there was a Christmas challenge. This was specifically aimed at getting the children working together and more comfortable with each other. Dominant personalities were already apparent within the group and I felt that the more shy ones may suffer if they did not feel able to contribute to conversation, I hoped by doing this type of activity the shy children would get the opportunity to contribute vocally if they wanted to.

The challenge was to use a variety of materials, card, hardboard, clay, 3D printing pens, 3D printed components to make Santa and his sleigh.

There were 3 in each group, one with 2 girls and a boy and the other with 3 boys. I didn't put them in groups, I let them decide. I want the club to be a comfortable place where all children will feel relaxed and can be themselves, so I do try to keep it as informal and unstructured as possible, which gives them the authority and responsibility to make decisions for themselves.

The group with the boys had 2 of the most confident and vocal children but they were also younger. They managed to work together and help each other. They did not seem to be preoccupied with making a life-like sleigh or making Santa look as is traditional in modern depictions. Instead they had an idea, worked on that, then one of them had a different idea so they built that onto their existing idea. It was a really interesting method of working.

The other group split the challenge up into individual tasks which they each took responsibility for. The shy boy was in this group and seemed more confident in the group with his sister and the other girl. He was laughing along with them and seemed to enjoy working on a joint project. Although he had also brought his unfinished model from the previous week so wanted to do a bit on that too, which was fine.

Quotes/observation:
"Can I do that part with you? I think we'd both be good at that."
"Oh, I have an idea. Shall we make a box for his sleigh so we can open it to see presents?"
"Can we design a part for our sleigh on the computer and print it?"
"Could you put plasticine in the pen and draw with it?"

Name	5
Boys	3
Girls	2
Type	3D printing club
Cost	PPP
Age	9-13

Description

This was the first week back after the Christmas break. Everyone who came to this session had been before. The printer was set up on the table and the laptops and 3D printing pens were laid out on the same table with seat around for everyone to sit at.

One of the boys who had been really focussed on making his models has developed his own style. He creates little scenes measuring approx. 5x5cm. He creates little dioramas in this space and populates them with people, animals, creatures etc.

One boy who doesn't seem particularly interested in using the tools as a means of crafting, has been making what he calls grips in almost every session. I'm still not entirely sure what they're for but they look well-made and he enjoys showing them off to others.

The brother and sister excitedly told me that Santa had brought them a 3D printing pen for Christmas. The boy then showed me what he had made over the holidays. He was delighted with the models- they were ships from Star Wars. The other girl used the laptop again in this session and worked more on her shelter for her hamster. She makes an effort to talk to everyone else in the group and asks them what they are making and how they're making it. The others all really respond to her interest and happily tell her and everyone else what they're working on. She adds a great dynamic to the group.

Quotes/observations:

"I like walking through an unusual space on a computer game, but I want it to be more real. So, I am making some scenes."

"I've realised that when making a grip, if I make the inside more like the way the printer does it with the criss-cross structure, I can make things quicker that are pretty strong."

"Can we print this and then see what adjustments we need to make. I think I need to see it in real life now to see how I could make it better."

Name	6
Boys	4
Girls	1
Type	3D printing club
Cost	PPP
Age	6-15

Description

This session was set up like normal. The 3D printer on the table with laptops, 3D printing pens and iPad. The children were free to use whatever they wanted to.

After the girl had finished her first iteration of her hamster's shelter the previous week, I printed the model in advance of this class. She was really pleased with the model and excitedly showed the others. She then asked for my advice on how she might improve. We spoke about how she could make more space inside but use less material. This involved breaking the model up into separate components that would be put together after printing.

The boy who makes the grips and who made the dinosaur used the iPad again to make another creature. This time it was a knight like figure with lots of weapons. Once he'd finished designing it, he used the pen to make more weapons that would fit into the figure's hands.

The other boy was still making miniature figures and scenes like the previous weeks. He was also contributing more to the group and advising others when they were trying to do details which he had mastered by working on a small scale.

The youngest boy came by himself without his Mum staying in the other room for the first time. He was confident and unphased. He told us a story about his dream wall at home and that last year they wrote that they'd go camping and they did, in Spain. For the rest of the session he used the 3D printing pens to create the scene from the story he was telling us.

Quotes/Observations:

"If I make the scene good enough, I can use it in my stop-motion set that I got for Christmas."
"Oh, you do animation. I do too. I've been using plasticine since I was 3. I love it. I've made lots of stop-motion animations. Me and my Dad do it."

https://www.youtube.com/watch?v=uIa823PqU0Q&app=desktop

"This is so cool. I can't wait to show my mum."

Name	7
Boys	4
Girls	1
Type	3D printing club
Cost	PPP
Age	5-13

Description

This session was set up as normal, a 3D printer, laptops, iPad and 3D printing pens. There was one new boy who started today. He is 10 and likes to draw comic books.

The one girl who comes wanted to use the pens today. She decided she'd like to make a box/pot for pens. She said that although she really liked designing and making the shelter for her hamster, she also loves to use the pens. She said they allow her to be more creative and change her mind as she goes without being restricted by lines that if you delete them half the model doesn't work anymore. She seems to become chattier and happier to share her insights when she is busy with her hands. The seems to be the case with the boys too. When they first come in the rarely talk amongst themselves, only to those they came with. However, once they are working on something they start talking to the group as a whole.

The youngest boy wanted to try the iPad today. He spent the whole session constructing different models using the pre-designed parts available on Tinker Cad. He seemed to have passed the point where he thinks things might not be possible. Now moving parts don't cause him to reconsider how it might work, he just knows that the printer can print parts that others might assume were impossible.

The new boy brought some pens and pencils with him. He drew a super hero and used the pen to trace his drawing. He left a hole where the face would be. When asked he said it was because he was going to use a drawing pin to hang it up.

The boy who is normally shy brought along the new boy and now he is like a different child. He is chatty and confident. He was delighted to be the one to show his friend how to use the pens. By showing his friend how it works he seemed to gain some sort of confidence in his own ability and was then happy to chat to the rest of the group.

Quotes/observation:
"Can I show him how to use it?"
"I love this. How long will it take to print? Can we make lots?"
"Can we make a version of this with the pens?"
"The pens let me draw as I think instead of having to think, then think about how to do what I'm thinking and then doing it. I think I think faster than I can design on the computer."

Name	8
Boys	4
Girls	2
Type	3D printing club
Cost	PPP
Age	5-13

Description

This session was set up as normal with the 3D printer, 3D printing pens, iPad and laptops. There were two girls this week and 4 boys.

The girl who has been coming regularly brought her little sister who is only 5 to the class today. She was really shy as she came in and sat with her sister. Her sister showed her how to use the pens. As she was working it out the boys, particularly M------ who gave her some advice on making her initial drawing stick to the paper.

After the boys offered their help, they started to talk among themselves and the girls told us that they were going to be in a play the following week. Their Mum had made their costumes and they were making mock-ups of things they might add to the costumes like a hoop for keys.

The other two boys still tend to keep themselves to themselves and chat amongst each other. The new boy is extremely focussed on what he makes and seems to be a bit of a perfectionist.

I had taken along the model that the young boy had made on tinker cad last week, but he wasn't there this week. The others enjoyed looking at all the individual parts and the weapons that he had chosen. This resulted in a conversation about Minecraft which seems popular among all the kids who were there.

Quotes/observations:

"The plastic goes hard really quickly. If we used another material would it do the same?"
"Could we put other materials in the pens?"
"Does that mean we could draw electronics?"
"Is there any way we can get the texture more like the printer does?"
"I like the bumpy texture it makes it look handmade but much nicer quality than anything else you could make so quickly."

Name	9
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This was the first session that I did at Potter Around. This is a pottery studio in an old farm building in Kirknewton. The session was set up in one of their painting room around a big table. The 3D printer was at one end, laptops and 3D printing pens were placed around the table.

The class started with an overview of how to use each of the tools and then I left them to get going. 8 boys attended, all friends from the local primary school. One of the boy's mum runs the pottery studio. So, he was far more laid back and relaxed than any of the others.

One of the boys was really excited by the printer and repeatedly came up with bizarre and abstract ideas such as printing a box with a hinge that has a diamond shape vertically on top. He also wanted to take what had been 3D printed and use the 3D printing pens to add to it. For example, he asked me to print a head and then he used the pen to construct the rest of its body.

As is typical, since for some of them it was their first time, they struggled to get the pens to do as they wanted. After some experimenting though they got it working. Most of them used the templates that I had and traced around pictures, mainly of super heroes.

They asked that for next week could I print so green lantern rings so they could all have one.

Quotes/observations:
"What can't you print?"
"What is the biggest thing you've ever printed?"
"If we mash up this since it's a mistake, could we make new filament?"
"If you want to see what's possible just watch Angus, he always goes crazy and makes impossible things work."
"Look Mum, I made this!"
"Dad come and see what I'm making!"
"Mum come through and see."
"This is the coolest thing ever. I can't wait till next week."

Name	10
Boys	5
Girls	0
Type	3D printing club
Cost	PPP
Age	5-9

Description

This group was set up as normal. There were only 5 children there this week because the play that the girls spoke about last week was on.

The 5-year-old was back again this week and was delighted when I gave him the parts from his model that he designed on Tinker Cad the previous week. He wanted to build it right away, but his mum told him not to do it till later to make sure he made good use of the time they were paying for. After she left, he spent most of his time laying out the pieces in the correct place as if he was building it without putting them together.

One of the boys spent his time making grips. I'm not really sure what grips are but when I asked him, he said they were for guns. In reality they look like rectangles make of plastic. He does seem to be getting better at making them though.

The other boy is still making miniature things, the details on these are getting better every week and he seems to really enjoy the praise I give him for it. He never asks for it or hints for praise though, but he seems to thrive off it when I give it to him.

The other two, have quiet conversations about games they are playing. The newer boy seems to work on 1 super hero per week and makes them in a very particular style, always with a hole where the face should be.
The other one makes really ambitious models. He seems to be learning about internal structures and made what looks like the middle of a sphere today.

Quotes/observations:

"Why does the printer make that bee shape in the middle?"
"Why is honeycomb such a good shape for the inside?"
"Thanks. I wanted to try to make the colour look less one colour and more varied like paint so I've been putting in a colour and extruding just a little before changing the colour so that I can get the gradient of the colour change."
"I can't wait till I get home to make my guy."
"I could make him new tools to hold. What might a knight carry?"

Name	11
Boys	9
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This session was in a different room today. It's a self-contained space so less in the way of the rest of the studio. The printer, filament and laptops were set up on one table while the pens were on another just next to it.

I had printed the green lantern rings from the previous week. Some of the boys thought that the green was too bright and wanted to change the colour. To do this, they put a darker green into the pen and turned the pen down slow before using the pen as a paintbrush to add a thin layer of dark green onto the surface.

One of the boys wanted to make a rocket on the 3D printer but wanted it quite big, bigger than the printer was capable of. To make it I suggested that they use the pen to trace out the shape and colour in each face before putting it together.

Another boy wanted to make something that moved. He decided that he'd make a box with a hinged lid. So, he did. He asked for some help when he was making the hinge because he couldn't quite visualise how the hinge would attach to the box. I demonstrated and he understood and managed to make his hinge.

Two of the boys used the laptops with the CAD software. One of them explored the other tools managed to build an abstract object which he transplanted into an Edinburgh street using the google street view function.
The other played around making a house. This method of exploring with nothing particular in mind seemed to work quite well as he just pressed undo when something didn't work and seemed to grasp the software quite quickly by doing this.

Quotes/observations:

"When the printer is making moving parts how does it manage to do it?"
"I like the software. it's a bit like drawing but I like that you can see all the way around it."
"I like the bumpiness of the top of the box. It could probably be used to let blind people read messages. Maybe I've accidentally said something on my box without knowing."
"Could you turn your 2D printer into a 3D printer?"

Name	12
Boys	5
Girls	0
Type	3D printing club
Cost	PPP
Age	5-9

Description

This group was set up as normal. There were 5 boys and it was one of the boy's birthdays, so I brought along a birthday cake for us to share and printed some yoda heads since the birthday boy is a Star Wars fan.

We all got started making things, most of the boys started something new but one boy continued working on something that he had started the previous week. The birthday boy was really happy and excited and spoke constantly about his birthday party which was to take place at Ryze trampoline park this weekend. He also told the other boys about the presents he got which included some Lego and a computer game for his Xbox.

I got the cake out and lit a candle and we all sang happy birthday. I cut the cake so that everyone got a slice. One of the boys said that he didn't like getting his fingers sticky and wished that I had brought some cutlery, so he decided to make his own. He used the 3D printing pen to trace out the shape of a fork and then built up layers to make it more substantial as a usable utensil. The other boys seemed to like this idea and they all joined in, making forks, knifes, plates and even a spork which one boy took great delight in explaining how it worked to the youngest boy of the group.

The birthday boy said it had been the best birthday ever and he wanted to save a bit of the cake to keep forever to remind him of the day so he used the 3D printing pen to wrap a small bite of cake in plastic until it was entirely encased.

The rest of the session revolved around the boys discussing the benefits of their plastic cutlery over disposable plastic cutlery, trying to find a way that they might be able to say that theirs was better.

Quotes/observations:

"I like how we can realise that we need something and just make it immediately. In the future we won't need to carry anything around with us except for a 3D printing pen."
"Could we turn every spoon into a spork by chiselling away gaps for the fork part and sharpening the handle?"
"I'll make a knife for your fork if you like?"

Name	13
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This session was set up in the side room of the pottery studio again. The printer was sat on one table with the filament, templates, paper and laptop and the other table was set up with 3D printing pens.

One of the boys asked if they could just download an image from google and print that on the printer. I explained that it didn't work like that but there was a website called Thingiverse where you can search through 3D models and download those to 3D print. He wanted to see so I showed him. This got lots of interest and led to 5 of the boys sat around the one laptop watching as they called out different ideas. They settled on Batarangs, a batman boomerang. I showed them how to download it and take it into Cura to prepare the file for the printer. I showed them the different slicing settings and chose a low resolution of 0.2mm to ensure we could print one in the time we had left. I then demonstrated how to set the print on the printer. This was the first time that they had been shown the process from start to finish and though it was relatively time consuming over the course of the whole class I think it was worthwhile as it seemed to connect the separate steps so they understood the whole process. There were several exclamations of "ah!" throughout. They all asked that they get a 3D printed Batarang for the following week.

As one of the boys had designed a house on Google SketchUp the previous week, I had printed that for him. He seemed slightly disappointed with the size. As he was working freely, without measurements on the computer when the drawing was scaled down to print the walls appeared shorter than he perhaps expected. After a few seconds he seemed to adjust his expectation and was really happy with it and ran through to show his Mum. He set straight to work on designing a table for the house, which was to be printed the following week.

One boy was interested in the slow setting of the pen which allowed him to draw in the air. He struggled initially but once he got the hang of it, he was able to make lots of strands stand up. I asked him if he planned to do anything in particular with his new skill and he said he wanted me to get translucent filament so he could make things that appeared to be floating in the air.

Quotes/Observations:
"So, we can search for anything, save it and the print it? That is so cool.... Wait, is that how it was when people were printing 2D pictures?"
"Can we just make it really small, so it prints in seconds?"
"What happens if we change the layer thickness to a centimetre?"
"I can't believe I designed this and now it's a proper thing."

Name	14
Boys	5
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

The Scout Hall we normally hire was closed indefinitely today due to its roof collapsing in, so we had to find an alternative space. Due to having only 5 hours notice I was not able to find premises but one of the Mums offered her house to host the club. So, we set up in her livingroom and all the regular boys still made it along.

The change in venue added excitement to the day so the boys behaved differently from how they might normally act. The quiet boys who tend only to speak to each other were nearly silent for the whole hour but were happily focussed on making their superhero's and responded really well to the praise they were given. I soon realised that their shyness signalled to me that they needed a little more reassurance than normal, so I made sure to sit with them at points and talk to them directly.

The boy whose house it was chattier than ever and delighted to have everyone around. He was far less focused than normal and spent most of his time playing host, looking out Lego men that the other boys might like to copy. He also demonstrated to his little brother who is only 2 how it works, and he looked on in fascination.

The other two boys' Mum/Mum's friend stayed so they acted a little different from how they would normally act too. They were more on 'best behaviour' mode than shy or overly chatty. They seemed to like being able to show her their progress throughout though. One of them made a Hulk figure, which all the other boys loved and told him, so which gave him lots of confidence and a big smile. The Mum who stayed is a jeweller and her son seemed to take inspiration from the conversation as he made a chain.

Quotes/observations:
"If we all worked together for long enough, we could make a new roof for the hall."
"Why don't we just make 3D printing club my house now? It would be so cool. We could even do it every day!"
"I'm not sure what I want to make today. I can't decide. Can I just doodle and see what I make?"
"One day I'm going to be the first person to every make a car using a 3D printing pen. I'll be on the cover of magazines and everything. How cool will that be?"

Name	15
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This session was set up in the side room of the pottery studio again, the same format as the previous two weeks.

I had printed off the Batarangs as requested by the boys the previous week. They were delighted and immediately headed out the patio doors into the field behind the studio to throw their batarangs in the air. A few boys came back in for some paper and they then took turns to hold the sheets of paper as targets. Soon the boys were hitting the paper and when the Batarang hit with the top of the wings it tore through the paper like scissors. They loved it. They all came back in and some decided to add to the Batarangs using the 3D printing pens to add some weight to make them fly better.

I had also printed the table the boy had designed the previous week. He seemed much happier with it this time now that his expectation had been adjusted. He took it in his hand and held it close to his face before examining it closely. He told me he was looking at the tiny lines on the table leg. He then used a ruler to measure the leg to work out how many layers there would be.

The same boy who was interested in Thingiverse the previous week was interested again and spent his time scrolling through pages and pages of files. He was fixated by the puzzle designed. He chose a cylindrical puzzle that was designed as a money gift box and asked for that to be printed for the next week.

Another boy decided that he would try to make a case for his phone using the 3D printing pen. He traced around his existing case and then drew on top of it. It turned out to be a good exercise in explaining the importance of tolerances in design. It took a few attempts to get the concept across, but he understood in the end and became much neater in his tracing in attempt to get a good fit for his case.

Quotes/observations:
"It is so light that it won't fly far outside but if we had a little weight it might fly further."
"Can we make a print heavier by adding material in the middle?"
"Are the lines on a print like the ring on a tree trunk?"
"It just keeps falling out even though I'm drawing round it."

Name	16
Boys	5
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

Due to the closure of our former venue I had to find new premises through the week. The class is now held at Currie Community High School at the same time (4-5pm) on a Thursday afternoon. The room is a classroom at the end of the school which has its own access from the outside sports area where there is a field, long jump area and basketball court. The space it a longer walk from the car park than the previous venue so the younger children need accompanied. The room is L-shaped, so I use the small square off to the side which is more than big enough to fit tables for up to 8 children to sit around with space for the 3D printer on the sideboard.

Due to the change in venue most of the parents ended up staying because they got chatting and by the time, they were going to leave there was no point. So, they sat at a table in the larger part of the room. This did not seem to impact the children's behaviour much though, perhaps they were far enough away, or the venue was neutral enough unlike the house last week.

The long jump outside seemed to draw the attention of the boys and 3 of them made a type of diorama of a long jump. They excitedly spoke among themselves about trying it out on their way home.

At home I have been experimenting with using templates to make drawings which I envisage will be useful for one off groups. I mentioned this to the boys, and they seemed interested in this idea and came up with ideas for things they might like to trace. These included sports badges, flags, bubble writing and animals.

One of the boys used the iPad to design a figure on Tinker play. He used the inbuilt selection of weapons to equip his character with as many as he could manage. He then seemed to make that the challenge, to give his character as many weapons as possible which meant that he was printing a lot more than necessary just on a whim without thinking much about it.

Quotes/observations:

"That's what is so cool about 3D printing, I can just give him as many weapons as I want because there's no limit. I love it."
"There is some limit. It uses plastic and it could eventually run out especially if it was near the end of a reel."
"I'm not sure what I want to make today, I kind of just want to go do the long jump. Maybe I'll make the long jump."

Name	17
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This session was set up as normal in the side room of the pottery studio.

The boys arrived straight from school and were happily and excitedly chatting away telling me about their day. Though they were never particularly quiet they seem to be used to me now and are not at all shy with me. I think most of them view our relationship as that of older sister and younger brother.

Two of the boys took laptops straight away. One wanted to design on Google SketchUp and the other to search through Thingiverse. The boy who was designing decided to make a phone cover as he had checked Thingiverse during the week and there was not one on there that fitted his phone. I explained that it would be tricky to get it to fit well so he needed to make sure that his measurements were as accurate as possible. The other boy just wanted to have a look on Thingiverse but as he opened the homepage, he saw on the header that there was a competition to win a MakerBot. He called me over to have a look. The competition was for children or groups/classes of children to come up with an educational device which could be 3D printed. The boy was really keen to come up with something and another boy heard too and joined in. I suggested they have a think about some ideas and see what else was available on thingiverse already if they needed inspiration. About 15 minutes later I went back over and asked how they were getting on and they were talking about designing a box that would fit in an exact volume of water, for example a boy that would hold a litre of water. I suggested that they design something that is not so big unless it really has to be, perhaps a ruler that is embossed with conversions. The boys though a while longer and suggested a set of keyrings that are exact measurements. For example, a cm, an inch, 5mm etc. They would all fit on the one keyring so the next time someone said that it was about an inch you could easily work out how big that was exactly or if you needed to tell something how big something small was you could use your keyring to differentiate between smaller measurements. I praised them for working so well and they were delighted and could not wait until the next again week so they could start designing it.

The rest of the boys used the pens. Some of them were just drawing squiggles and chatting while one of them was making precise geometric shapes.

Quotes/observations:
"I want to win that 3D printer. If I had a 3D printer I'd never need or want anything else ever again!"

Name	18
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	3-10

Description

This session was set up the same as the previous week in the new venue. Again, most of the parents stayed in the other part of the room and because of this the little brother of one of the boys also joined in and he is only three so significantly younger than the rest.

I had printed the figure that the boy had designed on Tinker play with all the arms and weapons. He was really happy with it and despite normally being self-contained and quiet he showed all the other boys and laughed at how many components he now had to put together. He spent the whole class building it and trying to work out where everything should go. He asked for a file so he could change some of the designs a little to make the shield design fit more with what he expected and so that it would be more effective against attack.

On seeing this, the other boys also wanted to build one too. In an attempt to encourage more learning and exploration I suggested one of them try Google SketchUp and the other Tinker play and then they could switch. Though they seemed more satisfied by the finished result of Tinker play while using Google SketchUp they seemed more animated as they were drawing out their designs. For example, one boy drew out a series of geometrical shapes one after the other and as he went, he said, 'this is the garden, and this is the house. The roof is dipped in so that when it rains it turns into a swimming pool and then the magical turtles come down for a swim and you can watch them as your lying in bed at night and the blue from the water lights up the room and you can see the turtles faces. Just like that.' The finished result of this did not look more than a few squares and circles pushed in and out but to the child it told a story. They seemed more excited to show their Mum's the Tinker play model, which looked more finished and like something you might buy in a shop.

The three-year-old who joined the class for the first time was perfectly content but also silent, sitting up on the chair with a 3D printing pen. He held it with both hands because it was too big for just one hand. He started off by making blobs but then he used the templates that I had printed off and drew around elephants, one after the other, each one getting even better than the last.

Quotes/observations:
"I want to do this every day for the rest of my life. It just makes me feel so good."
"Can I make another one next week?"
"Look Denise! Look what I made. I love it."

Name	19
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This session was set up as normal in the side room of the potter studio.
The boys who had been working on the Thingiverse challenge last week came in and took a laptop between them. They opened up google SketchUp and played around with different designs for how the individual keyrings might look.

The other boy who was designing the phone carried on with his design using the laptop. I realised that he was not rounding his edges so knew that it would not hold his phone tightly if at all. I explained fillets to him and told him why it was important. He then just used the arc tool to round it, I then had to clarify that it could not just be any arc, it had to have the correct radius otherwise with would not hold the phone either. This was trickier to measure. He ended up searching Thingiverse for a fillet gauge which we 3D printed so he could check what the radius of the curve on his phone was.

One of the other boys was using an iPad. He found the Thingiverse customizer app. Using this he downloaded the cover for his phone and used the drawing tool to removed square of plastic. On the back of the case he wrote the initials of everyone in the class. He was really happy with it and when his Mum appeared to drop his sister off at a pottery class, he was so excited to show her.

The other boys were mainly using 3D printing pens to trace templates. Since this group is made up largely of one group of friends they get easily distracted and could easily end up having nothing to show for their time and while that does not bother me, I am aware that their parents pay for the class so probably expect them to go home with something to show them. So, the templates work well for those who might otherwise sit just chatting, while chatting they will trace something and go home with something.

The boys who were working on the Thingiverse challenge had not achieved much by the end of the class, but they had learned a bit more about the software. Google SketchUp is easy for producing concept sketches but if you need to produce accurate, to scale models it requires a little bit of skill and patience, which the boys are developing.

Quotes/observations:
"Mum! Look what I've made. Next week I'll have it in my hands. How good is that?"
'"It's really hard, but we did get that bit working. Look, the hole goes all the way through."

Name	20
Boys	10
Girls	0
Type	3D printing club
Cost	PPP
Age	5-9

Description

This session was initially set up the same as last week but as more kids arrived, I had to change it around so everyone could fit in. Therefore, the large rectangular space of the L-shape was filled with tables to fit everyone around. Although there were only 10 kids there were at least 15 other people there too which included parents and siblings.

I set everything up as normal and let the regulars continue as normal. For the new children I crowded them rounded myself and went through format of how we run the sessions. I demonstrated the 3D printer, showed them Google SketchUp, Tinker play and the 3D printing pens. Everyone got started on something.

Because there were so many new children at once there were quite a lot of questions and hands raised for help in getting the 3D printing pens loaded. The children who normally come were great and helped me get around everyone to make sure everyone knew what they were doing. The boys love the opportunity to show off what they had been working on and telling them what they had done in the past.

One of the new boys Mum's took me aside to tell me that her son had motor function delay and so he might struggle a little more than the others. This mean that when using the pen, he would push the button, but his brain would not register that he had pushed for a fraction of a second which would result in the pen often not working in the way he anticipated.

Two brothers started, one who was 8, the other was 5. The 8-year-old was thrilled by the idea that he could make real things. He started off by trying to write his name but got fed up when it would not stick in the way he expected right away so he asked me to remind him how to draw in the air. He then sat in near silence for the rest of the class working on drawing in the air. His mum commented that she had never seen him so quiet. His brother was more frustrated when it did not work the way he expected and was determined to make it work. He asked me to help him. He wanted me to do it for him. Instead, I got him to do it, but I placed my hand on top of his to hold the pen upright and against the paper. I held it like this for a while before telling him I was going to let go. When I let go, he stayed upright and against the paper and was able to do what he wanted.

Quotes/observations:
"I've never seen anything cooler than this. I want to do this for my whole life."
"Fergus just said to me that when he grows up, he wants to do what you do Denise."

Name	21
Boys	8
Girls	1
Type	3D printing club
Cost	PPP
Age	9-12

Description

This session was set up as normal in the side room of the pottery studio. This week there was a new child who joined, a nine-year-old girl.

The boys got on with things as normal, those on laptops and iPad and the rest using 3D printing pens. I spent time with the new girl to show her the different things she could do. She was very shy but seemed keen to use the 3D printing pens. I asked her what colour she wanted and helped her load the plastic for the first time. She took a love heart template and started working on that.

I went to check on what the other boys were up to. Over the week I had printed the phone case for the boy who had customised one using the Thingiverse customizer app. He was delighted with it although it turned out that he picked a case that was not for his phone but just the closest he could find, and he reckoned he could make it work. So, he used the 3D printing pen to adjust the size, melting the parts that were too big or thick and adding more where it needed to be bigger or thicker. Despite it looking less than perfect he was delighted to have been able to make it himself and that it looked hand made.

The other boy who had been designing his phone case from scratch on Google SketchUp had asked me to print his first prototype and I had. It was too big, and the outside shape felt too bulky. He did not seem disappointed though and merely marked on it what he needed to do to improve it and started improving the model.

The boys who are working on the keyrings got a little further today though get easily distracted. I am not sure whether it is because they are working as a pair on the one laptop. This seems to work when exploring a software but when trying to achieve something in particular it may hinder them in achieving this as quickly as it could be achieved. I will probably have to spend time with them next week getting them focussed on the task again otherwise I can imagine that they will lose interest.

The new girl got the hang of the pen and made lots of different picture and tried putting different things together. When her Mum came to collect her, she did not want to go and despite her Mum telling her several times that it was time to go she ended up staying an extra 15 minutes.

Quotes/observations:
"There's a girl here! Has there ever been a girl who did 3D printing before?"
"I like that you can tell that I made it. It would be boring if it looked bought, what is special about that?"

Name	22
Boys	12
Girls	0
Type	3D printing club
Cost	PPP
Age	5-11

Description

This group was set up the same as the previous session with the tables set up in the larger part of the room.

There were even more new children this week, so I made sure that all the regulars were fine working by themselves for the first while. I told the children who were just there for their second week that if they needed a recap that they could come and hear me talking to the new children.

Most of the parents set up at a table in the smaller part of the room and seem to treat it as their own social occasion. This seems to work well for most of the kids and especially as there are so many under the age of 8.

One of the boys seems particularly shy and wanted his Mum to sit next to him. He was using the pen initially but then his Mum told me that he was quite interested in using a laptop to design something that could be printed on the 3D printer. I pulled a laptop over and showed him some basic commands before leaving him to it.

The boy who make all the super heroes without faces has been work on something about 5cm squared for a few weeks. Today he had a big pile of plastic lines next to him and when I asked him what it was, he said it was his first 13 failures of the day afternoon. He said it without any hint of frustration or disappointment. I asked him how he was getting on with it now and he said that he thought it was working now but he might start again if it did not work the way he wanted it to.

One of the new boys from last week made a flat shape that he could fit his fingers through. He told me it was a knuckle duster. One of the other boys suggested details that he might add to it to make it more effective.

Now that the group is quite large for this type of activity the social aspect of it has changed. Some of the quieter children are chattier and will engage with children they do not know and offer advice or share whatever they have learned or even made.

The new boy who wanted to use the laptop ended up designing a keyring for his Nana. He made a long thin rectangle and wrote “To Nana love Josh” on it in embossed letters. He also cut a hole through the model so we could put a keyring through it. He was delighted with it. His Mum sent me a text afterwards telling me how much Josh loved it and that he could not stop talking about it and that he was looking forward to next week.

Name	23
Boys	9
Girls	1
Type	3D printing club
Cost	PPP
Age	9-12

Description

This session was set up as normal in the side room of the pottery studio.

The new girl was first there and eager to get started. She does not talk much to me though does not seem particularly shy either she just seems interested in what she wants to do and today that was making her Mum a birthday present using the 3D printing pens. She picked a template that had Goofy and Mickey mouse in it and started working on that.

The boys arrived and were particularly rowdy chatting loudly amongst themselves. The three boys who are working on their own little projects quietened down almost instantly as soon as they got their laptops out. The rest carried on their fun while using the pens. Two of the boys had been having arm wrestles and then thumb wars, one of them suggested using the pens to design mini weapons for their thumbs to wear during the thumb war. So, they both started doing that and eventually almost all the boys were doing that. Some were just having fun with it and were not taking it very seriously but one boy in particular was meticulous with his. He put his 3D printing pen on the slowest speed setting to ensure that he could make it as neat and as accurate as possible. He also changed colour regularly to get all the details just as he was imagining so that it almost looked as though his thumb was wearing a crown type hammer-axe which was encrusted with jewels.

The boys who were getting distracted last week made the first part of their keyring, the centimetre part. I promised to print it for the next class. I had sat with them for a little while and we went through the competition rules again to get them excited again and imagining what they might do if they were to win.

The new girl made her Goofy and Mickey which were quite well made given that it was just her second class. By well-made I mean that all the parts stuck together, and it was thick enough not to break apart too easily. The girl still is not interested in talking to me but when I asked her what she was going to do in the big space she had left in between Goofy and Mickey she told me that she was going to draw a birthday cake with 39 candles on it. When her Mum came to pick her up, she made her wait outside and again stayed an extra 15 minutes longer than the class and I was waiting on her leaving so I could tidy up. She was so proud of her Goofy and Mickey holding a birthday cake 3D drawing though and I heard her say to her Mum as she was leaving that she could not wait to show her on her birthday.

Quotes/observations:
“We could make lots of thumb weapons and sell them. We could make a YouTube channel about them.”

Name	24
Boys	2
Girls	1
Type	3D printing club
Cost	PPP
Age	8-11

Description

This was the weekly session at the pottery studio, though it was the day after the bigger special workshop during the holidays, so it was unusually quiet with only three children attending.

As it was so quiet the boys wanted to print out some gliders that they could assemble. We quickly prepared the file and managed to reduce the print time to approximately 30 minutes which would still leave 30 minutes for assembly and playing with them.

The girl was super focussed as always and as usual not interested in chatting. She chose the letter template and traced out different letters and put them together to make the names of different people in her family. She had seen me make a stand for something I had been doodling. Since it was quiet, I sat at the table with them and did a drawing myself, I added a stand so that the relatively flat drawing could stand up. Initially the girl tried to just copy what she could remember me doing but when she could not get it as neat as mine, she asked me to show her how to make a stand. I showed her and she smiled at me and carried on in silence. She went on to make lots of names that stood up as if they were little name plates for desks. She kept lining them up and counting them, I think she was pleased with how many she was managing to make. She made 6.

The boys sat and doodled as they chatted about school and rugby. As the 3D printer was finishing off, they watched it and waited for it to cool down a little before pulling off their models. They pulled them off a little early, especially since the models were thin which caused them to curl a little. They flattened them out by and then assembled them. They used the 3D printing pens instead of glue to melt the parts together. They then took the gliders outside for a test flight.

Quotes/observations:
"If we melted up some plastic and added in some crushed metal could we put that through the pen and draw with it? That way we could make our glider fly better and look cooler."
"Why can't we just increase the speed of the printer? You did it to finish off that model a few weeks ago."

Name	25
Boys	9
Girls	0
Type	3D printing club
Cost	PPP
Age	7-10

Description

This session was during the Easter holidays so was a little different from usual though the set up was the same. Most of the parents had arranged to meet up in the outdoors sports area for the afternoon so the kids could run around together and do the long jump, which was always popular as they come and go from the club.

The kids came in and some parents came in and out with siblings. So, the club was a little more ad hoc than normal as kids came in and out as they pleased and younger toddlers ran around the room. The boys who have been coming since the beginning were as focussed as ever, working on their own self-initiated projects.

The boy who told me the pile of plastic next to him was his first 13 mistakes last week excitedly told me that he finished the foot of his iron man and showed me a block of red plastic. He was so pleased, and the other boys were excited for him to and told him that it looked really good and sturdy. This led to a conversation about the qualities of iron man.

One of the boys who tends to be a little less focussed and less likely to produce a finished item because of his tendency to get distracted worked on making a shovel type object so that he could dig in the sand of the long jump area. He was stood up as he was making it and got very involved in it, telling me each step of the way what he was doing and using his fingers to manipulate the hot, melted plastic. He kept running out with it to give it a test and would bring it back and tell me what needed fixing.

Another boy was fascinated by the idea that he could make moving parts so he made a cylinder and drew a ring that would fit on and move up and down it. He then added end stops on either side so that it was stuck on. He was really pleased with it and showed his brother and kept shaking it up and down and listening to the noise it made too.

One of the Dad's joined in and made a Hulk. He sat down amongst the children and was in silence for about 15 minutes as he drew around his hulk and started to fill him in. He commented that it was really addictive and soothing. He said he could not wait to come back the following week.

Quotes/observations:
"If the printer can make moving parts could I make something move too?"
"How hard would it be to design something that would move on the computer?"

Name	26
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	11-12

Description

This was the regular session hosted at the pottery studio. It was set up as normal with the 3D printer, 3D printing pens and laptops.

The class was back to its usual business today with 8 boys who came straight from school.

One boy was working on a laptop to design a table for the house he made a few weeks ago. Because it was on quite a small scale, he wanted to have the table set with plates, but he wanted them printed on to the table as they'd get lost too easily because they are so small.

The other boys used the 3D printing pens. Drawing the illuminati seemed to be very popular. I asked them about it, and they said it was a secret society that they were suspicious of other people being in. One boy made a 3D pyramid by drawing with the plastic in the air. Once he did this the other boys tried to do the same.

Quotes:
"Your illuminati are good; does that mean you are in it?"

Name	27

Boys	11
Girls	0
Type	3D printing club
Cost	PPP
Age	5-12

Description

This was the regular group at Currie High School set up as normal.

The class is really busy with new people who have joined recently.

The boys mainly used the 3D printing pens today although one boy did ask for Minecraft tools to be 3D printed.

Two boys were making gifts for their parents. One made a box that had a hinged lid. It was for his Mum. The other one made a relatively flat drawing of a guitar. When I expressed delight at hoe amazing it looked, he smiled and ran over to his seat show the other boys.

One boy who recently started has delayed motor function which means that he struggles to time the pressing of the button and how hard he has to lean on the paper. He seems to find this a little frustrating.

Quotes:

"Can we print Minecraft tools? I want to add them to my figures at home."

"Look what I made."

Name	28
Boys	0
Girls	2
Type	3D printing club
Cost	PPP
Age	9-10

Description

This was the regular session in the side room of the pottery studio. It was particularly quiet today as the boys were at school camp. There were just two girls who came.

The girl who normally doesn't talk much was still very quiet. She spoke a little more but only to say that one of the boys who was usually there, his Mum worked at his school.

The other girl was very chatty and spoke at length about her dog, her family, her haircut and school. When she was describing her dog, she used the 3D printing pen to draw him. After doing this she made him more 3D and then made a collar, a dog bed and bone for him.

She then asked if we could design a tag for him on the computer and then 3D print it. So, we opened up SketchUp and I reminded her how to work some of the tools. She made a pendant dog tag. I told her I'd 3D print it for the next again week.

Quotes:

"Can we make a dog tag for my dog? Then can we make charms to go with it? I love that we can just make anything!"

Name	29

Boys	9
Girls	0
Type	3D printing club
Cost	PPP
Age	2-9

Description

This was the normal group in Currie. It was also slightly quieter due to school camp. However, one boy brought his sibling along which made up the numbers a little.

It was one of the parent’s birthdays a few weeks ago so one of the Mums made him a birthday cake and brought it along. The boys were perhaps a little more excited than usual because of this.

One boy made a fork with the 3D printing pen to eat his cake with. After he had finished, he took a laptop and made what he thought would be a spork. However, he had just made a flat shape in the shape of a spork- a fork combined with a knife and spoon. I explained this but he said he didn’t mind.

The other boys mainly used the 3D printing pens. The younger brother of the regular boy is just 30 months old. He joined in today. I gave him gloves to wear since the pens are very hot. He used the pen to draw around some templates. He is very quiet and doesn’t show much emotion, but he did have a big smile on his face when I peeled the animal off the paper.

Name	30
Boys	5
Girls	2
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular group hosted in the side room of a pottery studio. Today is my birthday so I brought a box of cupcakes for the kids to eat.

One girl came in and commented that she was disappointed that she didn't know in advance that it was my birthday as she would have made me something. Then she asked that I not look at what she was making for the whole class. She made me a birthday cake using the 3D printing pens.

One of the boys made a case for his cupcake out of the 3D printing pens. He was trying to copy the case it came in. He ended up making a big cube which he crumpled up when another boy commented that it didn't look much like a cupcake case.

Two boys made miniature light sabres which they then used to duel with each other- the object being the first one to have a broken light saber loses.

Quote:

"What would happen if we made cases and then put them in the oven with cake mix?" This led to a discussion about the melting point of plastic.

Name	31

Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular group in Currie. One of the parents came in singing happy birthday. One of the boys realised it had been my birthday and ran over to his Mum and whispered something and she said she'd be back soon.

In the meantime, he sat and worked on something secretly.

The others mainly used the 3D printing pens. One boy made a super hero who doesn't have a face. He was quite pleased with it and used a small file to sand down some of the bumpy edges.

Another boy made a shoulder plate type thing for one of his action figures. It slipped over the figures head and clicked onto the figure. On the back of it there was a loop which would hold his weapons.

When the other Mum came back, she went over to the boy and then they came over to me with a card that had "Happy Birthday" written in plastic on the front. The boy was so happy with it and took it round to show the others.

Quote:
"This is my favourite time of the week. We get to do whatever we want, and we can use 3D printers!"

Name	32
Boys	3
Girls	2
Type	3D printing club
Cost	PPP
Age	8-11

Description

This was the regular session in the side room of the pottery studio. There was a new a boy and girl today. I showed them how everything works and then let them get on with it. The girl was really interested in making jewellery charms with so much detail.

The boy was a little challenging. He said he thought the printer was cool but that he wasn't interested in joining in. He was adamant and only wanted to play a game on the iPad. I asked him about the game, and he showed me. It was a battlefield game, so I suggested we make a real version of it. He liked this idea and together we started to make the board/ battlefield.

The other girl was very friendly with the new girl and she started to make jewellery too.

The other boys designed things on the laptops. One was making a figure and the other was just exploring the tools.

Name	33

Boys	8
Girls	2
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School after school. There were two new girls and one new boy today. After an introduction the girls chose to use the 3D printing pens and boy used a laptop to do some CAD modelling. The girls spent a while trying to write with the pens. Once they got the hang of it, they decided to start making birthday decorations for one of their birthday parties.

The new boy made a house on SketchUp and then moved onto the pens. He wanted to make a Hibs football badge.

The rest of the children were using the 3D printing pens. One boy was making a super hero to pin up on his wall. He has a very particular style when he is drawing with the pens and his models almost look like they've been knitted.

Another boy was making an action figure that had moving arms. He used files to file down the surface to get smoother movement.

"Denise, look! I made it move!"

"I think you could make that work better if you slowed the pen down."

Name	34
Boys	4
Girls	2
Type	3D printing club
Cost	PPP
Age	7-11

Description This was the regular session at the pottery studio.

The new girl from last week looked really happy when she came in and told me that she had been looking forward to the class all week. She planned to make a box that she could use to hold everything she made in.

The new boy didn't seem anymore interested that the previous week, so I showed him the website, Thingiverse in an attempt to inspire him with what is possible. This definitely seemed to make him more interested. He searched for different characters. He seemed intent on trying to find something that the website didn't have. He didn't manage to.

The other girl decided she would also make a box for her things. She chatted about her week to anyone who would listen.

The other boys were making copies of superheroes. One of them was sitting next to the new boy and kept making suggestions for things to search for. Eventually they settled on the head a of a king from a game so we 3D printed that. One of the other boys asked for a tiny one and he used the pen to model the rest of the body.

Name 35

Boys	9
Girls	2
Type	3D printing club
Cost	PPP
Age	6-11

Description

This class was set up as normal at Currie High School.

The girls came in chatting about the birthday party they had been to. They said that they were going to make a balloon with the 3D printing pen for everyone who had come to the party.

One of the boys wanted to make a better Hibs badge. He brought his hat so he could copy it. He got quite frustrated when the details weren't working in the way he wanted. I suggested that he reduce the speed and practice doing some squiggly lines close together.

One of the boys wanted to give the CAD software a go. He decided to make a keyring. I gave him a brief demonstration and then he took over. He was so determined and was silent for the rest of the class. At the end he had made a keyring that said 'Granny'. He was so happy with it and turned the laptop around so that everyone else could see.

Some of the other boys spend most of their time making toy weapons. They had seen them in games and wanted to have toy versions.
Sometimes I feel guilty about this and wonder if I inadvertently have a weapons club. I don't want to restrict their creativity or make them feel wrong or bad for it. I trust that the novelty will wear off and that by allowing them to continue it doesn't have any forbidden glamour.

Name 36

Boys	4
Girls	2
Type	3D printing club
Cost	PPP
Age	7-11

Description

This was the regular session that I do in the side room of the pottery studio.

The newest boy and girl were waiting for me what I arrived as they had gone there straight from school. While waiting, the girl did her homework, but the boy got some paper and drew a picture of the scene he wanted to make with the 3D printing pen. It included a helicopter. I know how difficult to get this boy interested so I suggested that together we make the helicopter and we could make the propellers on top, spin. He looked excited at the prospect and excitedly said, "can we really?". I drew out the side, front and back elevations of the helicopter and got him to make the bottom and top by sliding the speed down and slowly filling in the gap. Once we had the body, we could make the centre cylinder and then the blades with a circle at the end. We then threaded them on and made an end-stop for the top. Now we could spin them with our fingers or even blow them.

The others in the class mainly used the templates and one chose to make a toy sword on the 3D printer.

Name 37

Boys	9
Girls	2
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School.

Neither of the girls had tried using the laptops before to design things for the 3D printer. I asked them if they wanted me to show them how. They nodded and just as I was about to show them, one of the girls jumped up and said, “Oh wow, look what that thing is doing.” Despite the printer being there every week, she hadn’t noticed it. She then asked lots of questions about what each of the parts does. Once she understood how it works, we sat down at the laptops and I gave a brief demonstration of the tools. They seemed excited ad I left them to it while I went to help other people. Someone wanted a reminder of how to draw in the air as it kept collapsing for him. I showed him and he said it was so hard. I reminded him how long it took him to be able to draw flat but with practice that he became amazing at it. He said ‘Oh yeah. Okay. I’m going to spend the whole class just drawing in the air and then next week I’ll be much better.”

One of the other boys said that, “this just proves that practice really does make perfect.” I went to check on the girls. They had made some blocks and 3D shapes but seemed disappointed. They said they’d rather use the pens for now because the software was tricky.

Name 38

Boys	3
Girls	2
Type	3D printing club
Cost	PPP
Age	7-11

Description

This was a regular session in the side room of a pottery studio. After the success last week with the new boy I decided to get him engaged before he became rebellious about it.

Since he likes playing games on the iPad, I showed him the app, 'Tinker play'. Using this I showed him how he could design a character and we could 3D print it. He looked excited and sat for the whole session making it. Unfortunately, when I show this app everyone wants to make one and with the average print time being 7hrs per character it isn't ideal. So, I suggested that we all make characters with the pens. I made a couple of little figures that they liked but struggled to get theirs looking neat. I showed them how to use the heat of the pen to melt the plastic to give a smooth finish. This worked better.

Two of them then used the laptops to design their own things. The girl drew an outline of a horse to turn into a necklace.

Name	39
Boys	9

Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular weekly session at Currie High School after school club. After the girls had tried some 3D modelling on the laptops last week, two boys came in and immediately asked if they could try. The younger of the two boys had a figure with him from one of his games and he wanted to make another one. The other boy wanted to have a play around.

The girl was a little quieter today without her friend being there although she did seem to improve a lot with using the 3D printing pen. She kept persevering and became much neater at drawing with the 3D printing pen.

Two of the other boys were making weapons. One boy made a bow and arrow and the other one made a crossbow. One boy had brought rubber bands with him, so they were able to make their weapons 'shoot' the arrows.

The younger boy who was using the computer to replicate his figure realised that it is not quite as simple as drawing the outline and pulling the shape out. Although he was still happy with his shape. The other boy had made a 'landscape' of big chaotic shapes. He said he thought that it looked cool.

Name 40

Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	9-11years

Description

This was the regular weekly session at the pottery studio.

The newer boy and girl were there when I arrived again. The girl was really excited to get started. She was staying at the studio for a painting class afterwards and had brought a photo of her cats to paint. So, she decided she'd like to try to replicate the cats using the 3D printing pens too.

Again, the boy was quite reluctant to actively take part. I let him choose something to print from 'Thingiverse' which he seemed to enjoy doing.

The other boys were excitedly talking about their high school visit as they are going to high school after the summer. They were really engaged in conversations which let to all of them just doodling with the 3D printing pens rather than making anything in particular. For example, one boy was drawing squares and then colouring them in. In the end he had several plastic squares which he arranged and melted together to create a cube.

Name 41

Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular weekly session held at Currie High School.

Two of the boys had been on their high school visit as they are going to secondary after the holidays. They were a little less confident than usual and perhaps acted a little overwhelmed. They sat quietly together. One made a super hero and the other made a little figurine on a stand. I spent a little bit of time giving them focused attention and after we chatted about their day and games, they were playing they seemed a little more happy and secure.

The girl brought her model from the previous week and continued to work on it. It was a basket for a dog. She made the dog fit in it. She tried different methods for the dog including making each limb separately and making it in two halves. This option seemed to work best for her. The other boys were using templates. The super hero ones are very popular.

Name 42

Boys	5
Girls	1
Type	3D printing club
Cost	PPP
Age	9-11

Description This was the regular weekly session in the pottery studio.

This week two boys came in straight away and asked to use the laptops. One boy was determined to make a sphere. I told him how I would do it, but he also used 'YouTube' and blogs posts to do it. He was focused on it and spent the whole session doing it. He eventually got it almost perfect, just with one flaw.

The other boy wanted to make a trophy. I had an instruction sheet for this that I had made for a class last year, so I gave it to him, and he mostly followed it.

Another boy used the customizer 'thingiverse' app to personalise a phone case. When his Mum came to pick him up, he was so excited to show her.

The girl was just doodling most of the time today but seemed to get the idea at the end that she wanted to make a phone case next week.

Name	43
Boys	6

Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description This was the weekly session at Currie High School.

It was a little quieter today because one of the families were away on holiday.

It was much calmer and it felt like it was nearly silent for the hour as everyone was just working on their own personal projects.

One boy was trying to make a guitar type box. He wanted to make it box shaped and the wrap elastic bands around it so it could be strummed and then he wanted to make a cone shaped amplifier for it. He quickly realised that he would need to make sure that every tiny hole would have to be filled to make sure that the sound would echo.

Name 44

Boys	9
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School.

It was a little more hectic this week with it being busier.

The boys who were away came back with a type of bouncy ball they got while on holiday. One of them decided that he was going to wind plastic around it using the 3D printing pen. He spent most of the hour doing this and when he was happy, he bounced the ball. It kept cracking but because it was woven around it, it didn’t break. He laughed and seemed to think this was great fun.

The other boy wanted to make a stand that he could bounce his ball into. So, he spent most of his time making this.

The girl made a keyring that said Gran. She layered the plastic up in different colours.

The boy who had the 13 failures last week was still working on his bigger super hero although it still just looks like a big red lump of plastic.

Name	45
Boys	4
Girls	1
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular weekly session at the pottery studio.

The girl had planned on making a phone cover today so when she came in, she drew around her phone and started making it. When she got to the sides, she realised she'd have to cut bits away as she had blocked up the charging port and volume control. Once she fixed this, she realised that the edges had to just catch the phone and no more otherwise it wouldn't fit in or stay in. She did eventually get it working. She went into the other room to show her painting teacher and seemed really happy with it despite it looking quite rough and bulky.

Two of the boys worked together to try to make a fishing rod. This started when one of them tried to draw up into the air very high and it fell over but didn't break. Instead it bent and looked like a fishing rod.

Name	46

Boys	8
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the last term-time session at Currie High School. Most schools finished up yesterday, so the kids were quite excitable.

The girl came in and was talking about her holiday. She is going to Turkey. She said she wanted to make sunglasses, so she drew some frames and made the legs. They looked a little rustic, but she was delighted with them.

One boy who is quite ambitious in his makes, made a hinge on each of the legs so they could fold. He looked really happy and enjoyed the other children coming up to him to see and then comment on how cool they were.

One of the boys is going on a camper van holiday so he drew a camper van and a sun. He then wrote some words in Spanish that he had learnt for his holiday.

When asked everybody said they wanted the classes to continue during the holidays.

Name	47
Boys	9
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the first holiday session at Currie High School. The class took place in the library as the usual room was unavailable. There were two new boys who came along for a shot as they are not usually able to make it during term time. One of the boys has severe ADHD and he was quite challenging. In what is normally a laid back and quiet class. He asked lots of questions about the printer and was quite demanding. He wanted to print a ninja turtle toy however there were other children waiting who had also asked to print something. Eventually he was content for me to help him make one with his 3D printing pen and for him to be added to the list for next week. His brother was much quieter and tried to help answer some of the questions. He made a red Charmander Pokémon.

The Mum of the two new boys was concerned about the environmental impact of using so much plastic. Two friends who are boys were very focused on their work. One of them is continuing to make an Iron-man and the other is making a track for a little slider to slide along.

Name	48
Boys	2
Girls	8
Type	3D printing club
Cost	PPP
Age	6-15

Description

This was the regular 3D printing club in the pottery studio, but it is the Summer holidays and so people who are not usually able to come can.

Since there were only a couple of children who had been before I did a full demonstration of the 3D printer and printed some little figures.

I then showed them how to use the 3D printing pens. There was a big range of ages and the older ones seemed to get the hang of it quite quickly. I had templates out and suggested that people start by doing their name or drawing themselves before attempting anything more complex. This seemed to work well.

There was a younger girl who was struggling to get the plastic to stick to the paper. Anytime she lifted the pen off the paper she forgot to let go of the button and so it got messy quite quickly. I worked with her for a while and got her just to practice doing lines, tracing over a little template I made. This worked and by the end she was able to draw something that resembled what she intended to do.

A boy who I was told struggled with focus was really great at using the pen. He said it was really hard to do but seemed to be enjoying the challenge. He made his name and then enjoyed playing with the filament so that it would extrude different colour mixes, for example when he changed from green to blue there was a turquoise colour.

One girl got really into it that she didn’t want to leave when her Dad came to collect her. She ended up staying nearly 30 minutes late!

Name	49
Boys	4
Girls	5
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was a regular 3D printing club at the studio where most of the regulars came along with a few extra girls.

I let the regular get on with whatever they were working on and did a mini demonstration for the new people. There were three new girls who were friends and they were really keen to make jewellery. They said they liked the bangle that I had as a sample. They decided that they would each make one another a friendship bracelet.

They struggled a little initially, but they helped each other a lot and within a few minutes they all had it working well enough. They chatted as they worked and when they left, they said it was one of the best things they had ever done.

Two of the regular boys spent time searching on Thingiverse, they wanted to see if anyone had made a character from a new game they were playing. Another boy used the laptop to design a name plate. He took lots of time learning how to curve the edges in the way he wanted.

The regular girl who is quite quiet made a model of a tent as she said they were going camping, so she was making it for her Mum.

Name	50
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular 3D printing club at Currie high school. As it is the Summer holidays, we were in the library today.

It was quite quiet today and they boys barely spoke; they were all working hard on their models. One boy was making a football player on a spherical bottom so you could ping it and it would rock back and forth. It worked really well, and he looked really pleased with it and spent the rest of the time pinging it over.

One of the other boys was making a box with hinges. He had an idea for how he could get it to soft close like the newer kitchen doors you see. He used a rubber band and spent a long time trying to get the mechanism to work. It did kind of work in the end, but the model wasn't very smooth, so it was hard to see that it was actually working.

One of the other boys was still working on his Iron man. It still looks like a giant lump of red plastic, but you can just about see that it is taking form now.

One of the other boys asked to have a Bulbasaur printed on the 3D printer. He spent his time making a pokeball with the 3D printing pen which would contain the 3D printed Bulbasaur. It looked really great and he was really happy with it and said, "this is better than anything you could buy!"

Name	51
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular 3D printing club in a local pottery studio. The session was attended by the regulars.

Pokémon has become very popular this summer, and everyone wants to make them. Most of the kids today had brought bundles of Pokémon cards with them and most of them made Pokémon's using the 3D printing pens. There is a game that runs alongside the cards and the kids were using the models they made for a more physical version of the game.

Each of the boys chose their favourite Pokémon and drew it. One boy is particularly good at getting a neat finish took everyone's models when they had finished and used his pen to melt down the bumpy bits.

They then spent the rest of the session playing their new version of the Pokémon game. They asked me to bring templates of Pokémon for next week.

The girl made some rings and experimented until she could get them to fit her. She said she liked what the girls were making in the last class she had been to.

Name	52
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular 3D printing club at Currie High School, still in the library as it is still the Summer holidays.

Pokémon was popular today; I had a bundle of new Pokémon templates which the boys seemed to like a lot.

One of the boys asked if he could use Tinker cad to design a figure. I said he could, and he spent the whole class trying out different arms, armour and weapons. His brother spent a lot of time watching him do this. He asked if he can do it next week.

The girl is the older sister of one of the regulars and she asked me to print her a unicorn. While it was printing, she made a baseplate for it to sit on when it was ready.

The rest of the boys excitedly spoke about Pokémon and the game Pokémon go, discussing the best pokestops and what they had managed to collect.

Name	53
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	10-11

Description

This was the first 3D printing club back during term time at the local pottery studio.

All the boys today have just started first year of high school. They were just walking up the road to the studio when I drove past them in the car and a couple got in. They were excitedly chatting about their new timetables.

When we arrived in the studio I set up as usual and the boys were very chatty and not completely into 3D printing today. They spent most of the time drawing Pokémon and talking to each other about what had happened. A couple of the boys seemed quite shy and unsure about high school but were happy to talk about it when I asked them as they were drawing.

Name	54
Boys	9
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

Today was the first day back in our usual room at the Currie High School 3D printing club.

The kids were quite excitable today- the kids in this group go to 5 different schools so they were telling each other about their new teachers.

Two of the boys used laptops to design model for the 3D printer. One tried to make a Pokémon while the other was trying to design a pokeball. I spent some time with the second boy trying to help him get the sphere working, he told me that the software can be glitchy so he would just keep trying.

One of the boys was talking about his new school project- the romans. He wanted to make model of the colosseum. He listed all the romans that he knew about and was so happy when I told him how impressed I was.

There was a new boy today who's Mum brought him and told me he had complex needs. He sat down and I showed him how to use the pen and he didn't say much else for the class. He sat quietly and wrote his name over and over.

Name	55
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	10-12

Description

This was the regular 3D printing club at the local pottery studio.

I arrived before the boys this week and set up the printer to make some small Charmander models.

The boy arrived chatty again but were excited to use the 3D printing pens and laptops.

Two of the boys used the laptops to draw their models. One was just doodling with software until it made what looked like a very impressive house. The other was making a keyring with his name on it.

Two of the other boys were using the Pokémon templates that I had brought along. The people at the pottery studio have cleared out a space in the main area for displaying the Pokémon characters that the boys have made. The two who were making Pokémon today loved putting their models on display.

Name	56
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular 3D printing club at Currie high school.

It is a year since we started the business, so I brought a cake and bottles of juice for the kids. It was also one of the regular boys' birthdays today, so we sang happy birthday to him. Everyone was quite excitable and happy after that.

The birthday boy carried on working on his iron man model and the other boy made a Star Wars model on a plinth.

The younger boy made some balloons for 'Wee Replicators' and chatted about how much he loves 3D printing. He said that his class were talking about technology at school yesterday and his teacher mentioned 3D printing and he had told her exactly how it works.

Two boys were really excited about having cake and they chatted non-stop as they were making their models. One of them was making a car and the other one made a model of Yoda using the 3D printing pen.

Name	57
Boys	6
Girls	2
Type	3D printing club
Cost	PPP
Age	9-12

Description

This was the regular weekly session in the local pottery studio.

The girls were talking to each other about a community race that is happening at the weekend. They said that both their Mum's are taking part, so they made 3D printed banners to encourage them as they were running. They asked if we could print some trophies on the 3D printer.

Three of the boys made Pokémon character with the 3D printing pens. One of them is making one the size of an A3 sheet of paper. He is determined to build it up and make it look really impressive.

The boy who doesn't engage much with the 3D printer sat with the iPad and used Thingiverse customizer to customise a plaque with his name on it.

The other boy had read about 3D printers that print 3D printers so decided that he'd make the frame of his 3D printer using the 3D printing pens.

The boys were mainly chatting about their experiences at the new school and what classes they are enjoying, they seem to enjoy home economics where they get to make food.

Name	58
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School.

I had printer the Tinker Play model that one of the boys had designed a few weeks ago. He spent most of the session building his model, he was delighted with it.

One of the boys brought in a handful of sand from the long jump that is outside the room we use. He said he wanted to make a sand bucket to make a sand castle with the sand. He spent the whole session making squares as neatly as possible to make into a cube.

Another boy seemed unsure of what to make so he started making oval shaped rings. He decided to join them altogether into a chain. Once he got it to a certain length, he decided to measure it along the side of the room. He was about half way so challenged himself to make it as long as the room.

Four of the other boys seemed to like this idea once it became really big, so they all started making their own chains.

The newest boy wanted to make emojis. He was talking about a system that he uses at school where he can easily express to the teacher how he is feeling. He decided to make emojis with the same idea behind it. He likes to come up and show me what he is made but otherwise is quite quiet and self-contained.

Name	59
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This is the first 3D printing club at a private school in Edinburgh.

The session takes place in a classroom in the junior school and starts immediately after school. There is a classroom helper who comes along and the teacher whose classroom we use was in and out too.

I was allocated 10 children; the organiser gave me 5 boys and 5 girls to intentionally make it even.

The session feels quite short as it is only 45 minutes and, in that time, I have to set up the printer and tidy up.

Today I basically just managed to explain how the printer works and gave each of the children about 5 minutes to try out the pens. They seemed to find it very difficult and had little control of how the plastic came out.

Name	60
Boys	11
Girls	1
Type	3D printing club
Cost	PPP
Age	8-13

Description

This was the regular session at the local pottery studio.

It was a busy session where all the regular boys attended. They were pretty excitable and chatted constantly. Initially they were all use the 3D printing pens and seemed to just be doodling but after a while one of them started making a cube which he turned into a dice. After that they arranged their own competition to see who could make the best dice.

Two of the boys asked for laptops so that they could make their dice on the 3D printer itself. One of them was careful and measure the lines out to make sure it was even, and the dots were evenly space. The other one was a little less particular with it and just put the dots where ever and pulled them out at different extrusion depths.

The quieter girl was there. She decided to make a plant pot for her Gran's birthday.

Name	61
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School.

Two of the boys who come together were talking about what they had made since they started coming to 3D printing club. One of them said to me that the other had a cork board in his room that were covered in super heroes without faces which he had been making since the beginning. He pulled out a list from the little folder that he brings that had about 100 names of different comic book characters that he was methodically working his way through. He forgot to bring the Iron Man that he is working on at the moment so moved onto the next smaller super hero for his wall.

One boy is really into ice hockey and is a fan of some Canadian teams. He got his Mum's phone and searched for the team badges. He then used this as a guide to make his own badges which he intends to add safety pins to so that he can wear the badges.

One of the boys had seen a desk ornament which has the ball swinging like on a pendulum. He wanted to make one use the 3D printing pen. He made the frame and then the ball attached to a thin piece of filament, but it didn't swing quite in the right way. Another boy said that the ball had to be weighted so he got a penny from his mum and stuck it onto the ball. The filament snapped. He kept trying until it swung a little bit better. He seemed really happy to have learned about weighting the ball.

Name	62
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the second class at the private school in Edinburgh.

It is really tight on time but today I got the pens out quickly so the kids could get started sooner and then set up the 3D printer afterwards.

It is a very young group and I had to keep reminding them that I didn’t expect them to produce anything that looked like my samples yet. I just wanted them to squiggle about and make a mess with the plastic. Two of them, one girl and one boy, did that and by the end of the session they had worked out how to get the plastic to stick to the paper and build some sort of layer. Once they got the idea, they relaxed a bit and just kept practicing.

For the rest of the children they kept trying to make something and so seemed to struggle to get a grasp of how to actually make the plastic work in the way they wanted.

One of the parents came in at the end and said that they seemed to just be making a mess- I tried to reassure her and the children still in the room that it was important to keep practicing and that they would all get the hang of it eventually.

Name	63
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

A few boys weren't there today because one of them is in hospital after he got injured. The group seems to be made up of two half, those who are friends with one boy and those who are friends with another. When they're altogether there doesn't seem to be any division but when one isn't there the others don't come without him- interesting.

The boys who did come said they wanted to make a present for the injured boy. One of the boys spent time on the laptop make a house using the Google SketchUp. The others made a 'card' for the boy. First, they made a frame which two of them worked on. Then someone else made a hatched pattern across the frame. Another one did some 3D lettering. And the others made a backing for it all. It looked really good once they were done.

The girl who was there carried on working on her plant pot. At one point she seemed to get a little bored of using the same colour building up layers, so she drew out some flowers to save for inside the plant pot.

Name	64
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School.

The boys came in and 5 of them were talking about Marvel- there must have been a new film or tv show about it. They all decided to make their own 3D printed mask of one of the characters.

One of the boys chose iron man and his mask looked amazing- he was really pleased with it and said a few times as he was finishing it- 'Denise, look!' and asked for advice on how I thought he should continue with it.

Another boy brought his big model that he has been working on for months and carried on working on it. He is really nearly done and looks so pleased with it!

The newer boy said he wasn't into Marvel so instead carried on making some emojis. He told me that he was making the heart eyed one for his friend that he walks to school with. He told me that everyone thinks he fancies her but that he doesn't, she is just really nice to him.

Name	65
Boys	8
Girls	1
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session in the local pottery studio.

The two siblings who come arrived before me and were desperate to get started when I arrived. The boy who is usually quite reluctant to participate was really keen to get started. I asked him what he was going to make, and he said he was making his football teams badge. He was recently chosen for a football team which is quite prestigious. After he started making it, I asked him about when he got picked and what it's like playing with them and he chatted about that more than I've ever heard him talk before.

The girl was really excited for her painting class this evening as she is nearly finished her painting. She said she couldn't wait to show me what she has been working on. She decided she'd make a 3D printed replica of the painting.

When the rest of the boys arrived, they used 3D printing pens too. They were talking to the younger boy about his new football team.

Name	66
Boys	8
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie High School.

The group was quite chatty today. It is nearly the October break and some of the boys are going away for it. This led to a group wide conversation about holidays. One of the boys said that he was born in Los Angeles and his brother said that he was too. This got the group interested and talking about America. One boy said that they could be an American president since they were born there.

The boy who has been working on Iron Man for months finally finished. It is huge and so heavy! He did it in his own drawing style which makes it even more special.

The other boys were impressed by the scale of the Iron Man and said they couldn't believe he finished it after all that time.

Some boys said they were going to start something today and, in a few months, it would be just as big.

Name	67
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular session in the local pottery studio.

This is the last session before the October break and the boys all seemed exhausted. They spoke about how tiring high school is and how much they can’t wait to sleep all of the next again week.

5 of the boys quietly used the 3D printing pens as they were chatting. They used templates, one boy found an old animal template and made some really delicate silver silhouettes. He was really pleased with them and made on for his Mum, sister and someone else who was in the studio at the time.

Two boys use the laptop and iPad. The boy on the laptop was doodling with Google Sketch up trying to learn how to curve a surface. The other was scrolling through thingiverse looking for ideas.

Name	68
Boys	8
Girls	1
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was a regular session at Currie High school but it was run through the October break.

The elder sister of one of the boys came along. She wanted to create a pen pot with a unicorn on the front. She is really good at using the 3D printing pens and really responds well to being told how well she is doing.

The boy who finished iron man last week was less focussed this week- he said he feels like he hasn't got a project anymore. I suggested that we look at his list again and see which one he wants to do next. He chose one and started.

Three boys who came together today were talking about Minecraft, they all recently started playing it again. They asked if we could print some Minecraft tools on the printer and they all made a character from Minecraft.

The newer boy was a little more confident today and joined in some conversations with the other boys. He made a little flower for his gran who he said he was going to visit that week.

Name	69
Boys	6
Girls	1
Type	3D printing club
Cost	PPP
Age	9-12

Description

The group at the local pottery studio was a little quieter today as it is the October break.

One of the semi regular girls came along. She wanted to make a birthday cake for her friend. She made a base with the 3D printing pen and then drew up in the air. She asked for help with make the sponge part neat as she drew candles out separately.

Two of the boys printed little build kits on the printer. These are small set that let you break out the parts you need and assemble them. They chose the bike ones. It was quite fiddly and they spent a lot time trying to make it fit together. They then used the pens to stick the parts together.

One of the other boys used the iPad to play around with tinker play. He said he didn't want it printed, he just wanted to play with the parts so he could make a drawing of it and use the 3D printing pen to trace around it.

Name	70
Boys	6
Girls	1
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the regular session at Currie High School though it was a little quieter as it is the October break.

One of the boys who is usually quieter chatted to me a lot today as he was making a super hero. He told me that he has just moved to a new house and has a bigger room. He said he couldn't wait to organise all the 3D printed super heroes that he has made.

A brother and sister who haven't been for a while came along today. The girl wanted to make a necklace for her and her best friend. She drew a heart with the 3D printing pen and then cut it in two. She then made it stronger and wrote on each half. She used some unmeted filament in place of a chain.

The boy had been helping his Dad fix something in the garden and wondered if it was possible to make tools using the pen. I said that it was, but they probably wouldn't last very long because it's just made of plastic. He said he wanted to try anyway. He spent ages on the start part of the screw driver to make it as neat as possible. He made a matching screw so that it looked like it would work.

One of the other boys wanted to make a postcard to send to his family's friends in Spain. He recently found out that you can send anything through the post as long as it has a stamp. So, he wanted to make a post card entirely out of the 3D printing pen. He told me that they had visited in the Summer and they went to the zoo together.

Name	71
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the third session at the private school in Edinburgh.

After some more encouragement more children just tried to doodle with the pens and got the hang of it better.

One girl made a snail. Her pressure wasn't quite right but she was able to make something that you could identify as a snail. She said she was just making a mess and that it wasn't working. Once we peeled it off the paper though she could see it on the other side which she much preferred and then said "it's a snail! Look what I did!" She looked so pleased with herself.

One boy managed to get the outline down for a Pokémon that he was making but after he did the outline, he wasn't able to fill it without making the outline pop off. He started to get frustrated, I said that he just had to keep practicing and showed him different ways to 'colour it in'. Once we did that, he managed a bit better.

A little girl burnt herself by taking her glove off and touching the end. She cried. We ran her hand under the cold tap, and I encouraged her to have another go. She wasn't keen but I helped her get started and by the end she had managed to write her name and draw a love heart.

Name	72
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the fourth session at the private school in Edinburgh.

The kids are definitely improving but they get frustrated very easily.

They keep forgetting that you need to lean quite hard and whenever they forget the stop and say that the pen is broken. I stopped the whole group when almost all of them had said it and told them that the pens work perfectly but we just have to learn to use them. Nothing that is 3D printed is ever broken because it can always be fixed as long as we acknowledge that there is a problem and we don't give up. I did a demonstration to the group again making it really clear how much you need to lean against the paper.

Once they got going again a boy said it was broken and one of the other said, 'no it's not. You're just having a problem and that is okay. Just keep trying.' The boy picked it up again and managed to get it to stick to the paper better.

Name	73
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This is the regular session at the private school in Edinburgh.

The group was off last week for the October break and came back today. 7 of them had forgotten how to use the pens so I did a full demonstration again. Amazingly once I did this, they all managed to make something. One girl has mastered it and drew out the weather as she has been learning about the weather in class.

It seems good when one child manages to get it working well as the other children can see and realise that they are capable of doing it too. After this girl made her sunshine and cloud, four of the other children had managed to make and colour in a shape.

The girl who made the weather ran out to her Mum afterwards and said 'Mum! Look what I made!' It was lovely!

Name	74
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	9-12

Description

This was the regular session held in the local pottery studio.

When the boys arrived two of them were talking about a youtuber they had watched. They said that they wanted to make a YouTube video about 3D printing. The asked if they could use the iPad to record the video. The boys got the others to do different things so that they could demonstrate how the printer and printing pens worked.

They set up a file on Cura and then saved it to the sd card. They then filmed themselves setting up the printer and printing. As the printer was warming up, they went around the other boys who were using the 3D printing pens and showed the camera how they worked and discussed the similarities between the pens and the printer.

Once the printer started the filmed the who print.

They edited the film and asked for me to post it to my YouTube page. They seemed really happy with the final result.

Name	75
Boys	9
Girls	1
Type	3D printing club
Cost	PPP
Age	4-12

Description

This was the regular 3D printing club at Currie High School.

The boy who started making a post card last week carried on with it today. He is trying to get the back really smooth so that the post man will be able to read the address on it. On the front he has drawn a sun and a Scotland flag.

The girl who made the necklaces last week wanted to make keyrings today. I had some keyring hoops with me which she loved. She said she could make them look like real keyrings now. She wrote each of her friend's names and kept writing on top of the previous layer to make it really thick and strong. She then attached the hoop. She went over to her brother and showed him and smiled a big smile when he looked impressed.

One boy was making a super hero and talking about his new Lego set that he has got. This started a conversation between most of the other boys about their favourite Lego. One of them has the Lego Mindstorms and was explaining how it can be programmed and that you can make robots and other cool things. The others seemed to like the sound of that.

Two of the boys then started trying to make Lego bricks with the pens. I explained that Lego has very tight tolerances so it wouldn't click on like real Lego. We also printed some fake Lego on the 3D printer which went down well.

Name	76
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This is the regular 3D printing club held at the private school in Edinburgh.

The children are finally getting the hang of 3D printing and are making some things that resemble what they are intending to make. Most children are using templates.

One boy was using a template with Darth Vadar on it and spoke at length about his favourite Star Wars film. He made some mistakes with his model, but he seemed too busy talking to care much and he managed to solve the mistake by carrying on without being bothered by the sticky up bits.

One girl wanted to make a name on a stand for all the people in her family. She was writing the letters one at a time and then attaching them to a line. She doesn't know how to do joined up hand writing yet so this is the easiest way for her to do it. She was so pleased when she got her first one to stand up. She had a big smile and did a quiet squeal of delight.

Name	77
Boys	4
Girls	0
Type	3D printing club
Cost	PPP
Age	10-11

Description

This was the regular session at the local pottery studio.

It was a really quiet session today due to parents' evenings. One boy was there said that when he gets a good report on parents evening, he gets to go to McDonalds, so he was really hoping that was what was for dinner. He made a box of McDonalds fries with the 3D printing pen. It looked really good and when I told him how impressed I was he looked really happy.

Another boy said he didn't care about parents evening and that he didn't get any special treats for doing well. He said that they go camping a lot, so he feels like he goes on holiday all the time. He was describing his tent to show that he has his own room. He ended up drawing a plan view of the tent and then started to trace it with the 3D printing pen.

The other two boys were using the laptops. One of them wanted to make their Dad a keyring for his birthday. He drew out a tag shape and then wrote Happy Birthday on it. We managed to print out a small version of it at the class.

Name	78
Boys	5
Girls	2
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular session at Currie High School.

It was quite quiet today because it is parent's night at a few schools.

There were two girls there today and they were excited because one of the girls was staying at the other one's for dinner. They spoke about being best friends and that they've even had sleep overs. I asked them what they do on sleep overs and they said they stay up really late. I sat next to them and used a pen to doodle a bit. I had seen some cool earrings at the weekend where someone had made pink wafer earrings. I told the girls about it and then made something that looked a bit like a Haribo fried egg. They loved that idea and carried on.

Three of the boys were talking about Pokémon and discussing which was the best Pokémon. I asked them about it and asked who would win in top trumps. They seemed to be excited about think about it like that and then made little score boards to sit in front of their models.

The quieter boy made a little trophy today that said '#1' and said it was for me because I always listened to him and helped him even when I was really busy.

Name	79
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

Three of the girls decided to make rings today. They started out by drawing circles, but one girl realised that they could draw directly onto their fingers because they were wearing gloves. I suggested that it might be hot, but they said they were fine, and it was the best way to get a ring the right size. By the end of the class almost everyone had tried making a ring this way.

One of the boys is really into sheep and he decided he would make his sheep really 3D. He worked really hard on it but right at the end he snapped it and said it was rubbish. He didn't seem upset though.

Another boy drew a stick person and then started explaining his different clothes and things. He finished by saying it is his imaginary friend but that now he is real.

Name	80
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	9-12

Description

This was the regular session in the local pottery studio.

It was a quite a quiet session today with only one group of the boys attending. One boy was talking about his rugby team, he is the only one who plays rugby, the others play football. The led to a discussion about the game that they used to play were little model footballers were on top of a half circle so that they would bob around. 4 of the boys decided to try and recreate them with the 3D printing pens. One of the boys wanted to try and make one use the CAD software on the laptop.

The one who was using the laptop said that he remembered that it was the ‘follow me’ tool that was used to get the model to curve around. He double checked a tutorial on YouTube to remind himself how to make it solid afterwards so he could do something on top of it.

As it was so quiet, I was sitting at the table with them doing my own thing with the 3D printing pen. The boys seemed much chattier with me. They always talk quite freely with me but when I was sitting down next to them and working away myself, they spoke about personal things- one of them told me about someone at school who he described as being nasty to him. Another one said that he had fallen out with his Dad at the weekend and he was away from home working all week. I tried to reassure them that things would be okay and that someone who is nasty to them might have a lot of stuff going on at home and that while it doesn’t excuse it does make us see that it isn’t necessarily got anything to do with us when someone isn’t nice and so as long as you are being nice and good then to try and remember that someone else’s thoughts and opinions should be accepted with the knowledge that it doesn’t change who we are or how good or kind we are.

It felt really nice to have the chance to talk to the boys like this- they seemed to get a lot out of it and when they left, they seemed happy.

Name	81
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular session at Currie High School.

The newer boy came in today and said that he wanted to make his Grandad a birthday present. He said that he really likes car so wanted to make him a car with the 3D printing pens. Another boy said that one way to do that is to draw the side views and the roof, then attached these together and then slowly build out the front and back to get the shape right. The newer boy seemed excited to get started and started immediately.

After this the other boy said he was going to make a car now too. He got distracted though and ended up making a boat. When one of the other boys saw that he was making a boat he started talking about the Olympics which happened in the Summer. He decided that he too would make a boat, but he made one that looked like the boats they used in the Olympics and not the standard stereotype of a boat like the other boy.

Three of the boys had been on a day out the weekend before and got yoyos. They wanted to make their own yoyo with the 3D printing pen. They chatted excitedly about what they had been doing.

One boy made another super hero for his wall. He was very quiet and seemed upset today. I went and sat next to him and he told me that he had fallen out with the boy who he normally comes with. That boy was sitting on the opposite side of the room. He told me that he was in the wrong and that he didn’t know why he had done what he had. I said that if he acknowledges that he was in the wrong and apologises for it that his friend would come around eventually.

I went and spoke to his friend too who seemed determined that he will never speak to the boy again. I said it was fine to feel like that but maybe eventually he would be less angry and be able to imagine how he would feel if he had done wrong and wasn’t able to fix it. He listened to me and said okay but he wasn’t done being angry.

Name	82
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

I set up today started printing some dogs on the 3D printer. One of the children asked if next week we could print Jesus since it was nearly Christmas. I said that generally I wouldn't mind doing that but that this print was for the whole class and it might not be appropriate to give every child a model of Jesus. She seemed confused so I suggested she make her own Jesus with the 3D printing pen.

The school are already working hard on producing the nativity play so all the kids are in full Christmas mode so today they were making Christmas trees, stars, snowmen and Santa clauses. The trees looked good as the children are still having a bit of trouble getting the pens to consistently extrude the plastic but when they make the trees like that it looks really effective. One of the children pointed that out and said, 'sometimes when I make a mess it looks better than I meant it to.'

One girl in the class is play Mary and she started to sing the solo that she has in this production. She forgot one of her lines, so she wrote these out with the 3D printing pen and said see, now I won't forget that one.

Name	83
Boys	6
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

After yesterday's class making Christmas decorations, I printed some Christmas themed templates. This meant that everyone wanted to make Christmas things.

The two girls made mini stockings and drew lots of presents in them. They then started making small cubes and decorating them as though they were little presents. They looked great and the girls were really pleased with them. They then made on for everyone in the group.

One boy was making a snowman but changed his technique half way through. He started to make small spheres of white plastic that he then wound the plastic around. After a while it started to build up and look like snowballs. He attached these together, so it really looked like a 3D snowman.

One boy said that he was going away on holiday over Christmas and it is the first time he'll be away. He said he isn't sure about it because it won't feel like Christmas if it is hot.

Another boy went on thingiverse and chose a Santa hat model which he asked me to print for next week.

Name	84
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular session at Currie High School.

It was really quiet today, so I sat and made things with the boys. It gave us all a chance to chat. This group weren't into doing Christmas decorations yet. One boy was making a hinge and trying to get a really smooth finish on it. Another boy was making a super hero. These boys still aren't talking to each other.

One boy told the group that he was going to the trampoline park that weekend. The other boys said that it was amazing there and then chatted excitedly about moves they had managed to do on the trampoline. One boy was trying to demonstrate how you do one move and ended up drawing it out with the 3D printing pen and then moved the model in the air to show how he moved.

Another boy wanted to make a box to keep his kinder egg figures in. He emptied his pocket on to the table to show us how many he had collected. So, he wanted to keep them organised in a box he made to fit them exactly. The group ended up talking about their favourite chocolates after that.

It was a really relaxed group today where conversation just flowed naturally without any self-consciousness. It was good.

Name	85
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular group at the private school in Edinburgh.

I showed one child how to make Christmas tree by drawing into the air. You draw a circle on the paper and then lift the plastic up. After it cools you add another strand and melt it at the top of the other one. If you do these ten times it starts to look really good. Then you can draw a star on the paper and attach it to the top.

After I did this every child wanted me to make them one. I encouraged them to try themselves as they waited for me to come around them all. Eventually I realised that if I said I'd help then they wouldn't try so I told them that I would only help once they had tried fifteen times. The kids seemed outraged and said they'd never manage it but after I did this no child needed my help- they all worked it out within their fifteen tries. The only time I helped was when one child was getting really overwhelmed and upset. I think it is a judgement call on whether the child needs the support or whether they just need encouragement to do it themselves.

One boy who desperately wanted my help, but I said only after fifteen attempts to said he couldn't believe he had managed to make the bauble for the Christmas tree. He held it against his chest and said, "I made this all by myself."

Name	86
Boys	4
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

I went in and started printing mini Christmas hats on the 3D printer. As the kids came in, they all asked if they could have one. One of them asked if they were pencil toppers- I said they weren't meant to be, I just scaled them down, but they could probably be used as pencil toppers. After this all the kids took pencils out of their school bags and started making pencil toppers.

One boy used the peach colour and made a hand with a finger pointing up and said it was to be used as a nose picker. The other boys loved this, and they all made their own one.

One of the girls made a big love heart on the top of her. The other one made a dog that looked really good. She said she was so happy with it. I spoke about how nice miniature things can be sometimes and she said she agreed and wanted to make more. She ended up making a little tea set with cups, a teapot, a chequered rug and cupcakes.

The other girl carried on making Christmas baubles. She spoke about her Christmas tree and said that each of her siblings gets to take turns in placing a bauble on the Christmas tree. She said it is one of her favourite things about Christmas. Two of the boys agreed and said that they love it. One of them gets hot chocolate as they are putting the decorations up.

Name	87
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description This was the regular session at Currie High School.

It was really quiet again, so I joined in with the boys. The two friends have finally made up and seem friendlier than ever which is nice. They were saying that they are having a sleep over this weekend and that they are going to play computer games all weekend. They said they'd play Marvel Ultimate alliance. I asked about the characters in it and who their favourites were. One boy held up the model he was working on and said him- captain America.

The chat on video games led to a discussion about the new console that Nintendo will release. They said it is called the switch. One boy said he really hopes he gets it for Christmas next year. They then started talking about how expensive consoles are.

One boy said that he isn't allowed to play computer games yet but that he likes playing the maths game on the pc at school. Another boy asked him what he does for fun. He said he reads and likes to play with his Lego. Another boy said he likes reading too but doesn't like the reading books at school. He said he has a book about space, and he loves it.

Name	88
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

This group is getting really excited for Christmas. All the girls said that they wanted Hatchimals for Christmas. They said they look so cute and they really hope they get one. Two of the boys said they want some sort of Skylander thing. The others said they didn't mind what they got.

A girl got so excited at the thought that she started making Rudolph a 3D printed carrot.

The other kids used templates that I had brought with me. They're all getting the hang of it now and are making things that look really good.

Two boys were making Christmas trees. One of them wasn't very happy with it because the plastic bumped up a bit. The other boy said not to worry because by the time it was finished you wouldn't notice it.

A girl asked for help and when I saw that it was just to get a big bit filled, I said I knew she could do that herself, so I'd only help once she had tried 15 times. She sighed but carried on. At the end she held it up and said "look! I made it all by myself." When her mum arrived, she showed her mum and told her the same thing.

Name	89
Boys	6
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

It is St Andrews day today and the kids must have had some sort of celebration at school because six of them made Scotland flags. The girl told me what they had learned about St Andrew and a boy jumped in to add some more that he had found out too.

One girl was making a union jack- I asked her why she was making that. She said that it was the other Scotland flag. A boy jumped in and said that it wasn't and went on at length about the union and how a lot of people are dissatisfied with it. He said that his Mum and Dad hate the union jack now because of what it has come to mean in Scotland. The girls said she didn't know that and asked if there were two Scottish flags though. I showed her the lion rampant flag and she said she preferred that one so started making that.

The boys were chatting about some teachers at school. One of them got in trouble today and was annoyed about it. After the other boys spoke about what happened, the annoyed boy said he was upset that he had been misunderstood.

Name	90
Boys	8
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at Currie High School.

The session was busier again today and much rowdier. The elder sister of one of the boys came along. She said she was going to make a unicorn badge for her jacket. She is really good at using the pens and seems to enjoy the notice she gets from other people when they see how good she is at it.

The other girl started making a unicorn too after she heard that is what the other girl was making. She said she loves unicorns and wishes they really existed. The other girl said they do!

The boys were chatting excitedly. Two brothers were talking about their elf who visits them every year from December 1st. They told the other kid's things that he had done in previous years. This morning though he left all the siblings some chocolate coins.

One boy said that he doesn't like chocolate, so he gets other things in his advent calendar like rubbers and pencils.

One boy said that he has to share his chocolate advent calendar with his sisters so only gets a chocolate every three days.

That same boy said he was going to make little treats for himself so that he gets something every day. He made a little candy cane, a little Christmas pudding and other small things.

Name	91
Boys	5
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

The nativity play is next week, and the excitement levels are really high. The kids sang Christmas songs for almost the whole session.

Three boys were drawing snowmen, but they were so distracted by the singing that they didn't get them finished. One of the boys wanted to make them scarves that match the school uniform, so he made one for each of the snowmen, they were really cute.

A girl was making a bracelet. She started off by drawing a circle and then wove other plastic around it. Some of the other girls were interested in what she had done so she did a demonstration for them. She then made a bracelet for each of the other girls in the class and me.

One boy was making a blob of plastic. He said he just wanted to see what would happen. He worked out that if he held the pen in one position the plastic would continue to be extruded but stay hot so have a much smoother finish on it.

Name	92
Boys	6
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

The kids are getting quite excited for Christmas and all of them made some sort of Christmas decoration today.

One of the girls made a candy cane by wrapping plastic around an unextruded piece of filament. It worked really well and soon after the other girl started doing the exact same thing.

One of the boys was making a present for someone at school. He had the inside part of a kinder egg and drew on it with the 3D printing pen until it looked a bit like a present. Inside he wrote a note. The other boys commented on how cool it was and tried to make something similar but without the inside part of the kinder egg they weren't able to easily make it pop open.

The boy who made it went running through to his Mum who was in the other room to show her. He came back in with the biggest smile on his face.

On the printer one boy wanted to print some Christmas trees. He found a file on Thingiverse and set it up in Cura.

We played Christmas music through the speakers and everyone was happily chatting to each other talking about their days and what they were getting for Christmas.

Name	93
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the regular session at Currie High School.

The brother and sister arrived today and said that they were going to make Christmas presents for all of their family. They both started by making boxes which they said were jewellery boxes for their grannies. However, both of them started getting a bit fed up when the sides were warping a bit- they were both making the boxes by drawing all the sides individually and sticking them together. As each side takes a little while to draw the temperature difference across the shape means that the plastic shrinks in different ways. Both of them decided to make Christmas decorations instead which were flat symbols around Christmas.

Everyone else was also making Christmas related things.

One boy used a laptop to make a little sign for his grandad. He made a plaque in Google SketchUp and wrote 'best grandad' on it. He did this right at the beginning of the class, so we had time to print it during the class.

Name	94
Boys	4
Girls	5
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the last 3D Printing session before Christmas. Everyone was really excitable and talking about their nativity and what Santa was bringing them.

I brought Christmas themed templates with me and everyone chose something Christmassy to do. One boy was making a snowman and wanted to make the scarf multi-coloured. He asked if everybody wanted to a stripe so that it was made by everyone. All the other children were excited by that and took it in turns to add their stripe. At the end of the class the boy who originally made it gave it to me to say Thank You!

One girl recently learned to draw stars using the ‘line to line’ method. She loved the gold filament and spent a long-time drawing tens of stars practicing the ‘line to line’ method. She gave a star to everyone in the class and took a handful home with her. She looked so happy with them.

Name	95
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the final 3D Printing session at the local pottery studio before Christmas.

The girl was making presents for her Mum and Dad. She made a stocking and then lots of tiny wrapped presents. It looked really great and she said she couldn't believe how well it turned out. She started making a Scotland flag for her Dad.

Two of the boys decided to make mini games that could be played at Christmas. One of the was making a knots and crosses set while the other one tried to make a solitaire board. They said they had seen mini games in the shops while Christmas shopping with their Mums and thought they could make some that were just as good.

One boy was searching on Thingiverse to find a Christmas decoration. He chose a flat bauble so that it would print in time. When it printed, he looked so happy with it and said it had printed really well. Everyone else wanted one after that but there wasn't enough time to print another 7 so I used the pen and did my best to make one similar for everyone. They were all happy with their handmade ones.

The other boys were doodling with the pens. One of them was making tiny little Christmas objects such as crackers and Christmas puddings.

Name	96
Boys	9
Girls	2
Type	3D printing club
Cost	PPP
Age	6-12

Description This was the last session at Currie High School before Christmas.

I had brought along some chocolate coins and juice. However, when I arrived all the parents were there and had set up a surprise Christmas 3D Printing party for me. They had juice, snacks, cakes, biscuits and prosecco. I was so surprised! I set the printer and everything up as usual. Once everyone got settled one of the Mums said that they each had something to say to me.

The each took turns to stand up and say something.

One Mum said that her son was shy and nervous before he started coming to my classes and now, he has confidence and much better self-esteem. She said that a teacher had commented on the improvement and that she knew it was because I encouraged him and never treated failure as failure but as an achievement on the way to making what they intended. She cried and said that I meant so much to their family for doing that.

Another Mum said that my unending enthusiasm made her feel inspired every week. She said that my classes were her and her son's favourite hour of the week.

Every Mum added something and when they were finished, they toasted me, and the kids brought me up a big present. It was full of gifts- a contribution from each parent.

Name	97
Boys	4
Girls	1
Type	3D printing club
Cost	PPP
Age	8-11

Description

This was the first session back at the local pottery studio since Christmas.

It was relatively quiet today with it being the first week back. Two of the children were already there when I arrived as they had gone straight from school. They were excited to tell me about their Christmas and New Year. They had been away for Christmas visiting their family and had taken them the 3D printed decorations they had made.

The other boys arrived a little later. One boy spent the hour on a laptop playing with the CAD software- he didn't make anything to print but experimented with the tools to see what they could do.

The other boys used the 3D printing pens. One of them drew a cartoon character that I hadn't heard of while the other made a toy knife.

The girl spent her time making pendants which she intended to turn into necklaces.

Name	98
Boys	4
Girls	1
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the first session back at Currie High School after the Christmas break.

One boy came in with a new toy called a fidget spinner. It is like an inverse triangle and spins around a bearing in the middle. It is very satisfying to spin. He asked if I thought we could make one with the 3D printing pens- I said I was sure we could. He took the bearing out of the middle of his fidget spinner and tried to replicate the bearing with all the individual balls inside. I simplified the design and made the outer shape, two circles and then drew a small cylinder on one of the circles which could be pushed through the middle of the shape and attached to the other circle. The boys design did work but the resistance was quite high because of the unevenness of the balls inside the bearing. My design didn't spin as fast as the real one but did move freely and was quite satisfying to spin.

The class was quite quiet, and the other boys and girl quietly worked on their own models. The girl was practicing her writing with the pens- she made one for everyone in the class.

Name	99
Boys	5
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular weekly session at the local pottery studio.

The two girls were chatting about what they did on holiday. One of them got a new baby cousin. She spent the session making a big letter 'S' for the new baby. She was really happy with it- it was pretty big.

There were two new boys who came along today. I showed the how the printer and pens work. They were fascinated and commented that it was like magic. They both struggled with the pens initially but after some help, they got the hang of it. By the end of the session they had only made their names and a couple of filled squares each, but they were so happy with them and said they couldn't believe that they had made them.

One of the other boys was using the CAD software to design a ring. He wanted to make it quite broad and then add a hole in it. He was really interested in the 'hidden faces' option on Google SketchUp. When deselected he could see the individual faces that make up a cylinder. He experiments with pulling faces out and pushing them in.

One of the other boys used the 3D printing pen to draw on his phone cover. He wrote his name and started to melt holes in it. He said he really liked the new look.

Name	100
Boys	5
Girls	1
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular weekly session at Currie High School.

After last week when we made the fidget spinners, lots of other kids have since got their own one. This led to them wanting to make them with the pens.

One boy was so excited that he got to choose his colours. He chose blue for the base and white for the finger pads. He said he wanted it to look like the saltire. When he was finished, he looked amazed that it worked and ran up to his Mum and said, "look what I made!" After playing with it for a while and comparing it with his shop bought one, he decided to try and close the gap between the base and the finger pads. After a lot of experimentation between the two of us it became clear that a wider gap is necessary to get a fast spin. He was frustrated by this initially but once he understood why he was happy and fixed his saltire spinner. He said he wanted to make one for his brother.

The girl in the group doesn't have her own spinner yet, she said her Mum will not allow her to get one. She was so excited that she could make one. She carefully chose the colours and concentrated really hard as she made all the lines melt neatly together. She finished it and came running up to me to show me and demonstrate the spinning. I told her that I was so impressed, and she gave me the biggest smile before running back to make her friend one.

Name	101
Boys	6
Girls	2
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was a regular session at the local pottery studio.

There was a new boy who joined today. After the printer demonstration and using the pen for a while he seemed frustrated by being unable to use the pens as well as the other boys. I tried to reassure him, but he started getting upset. I did an outline for him and he filled in the gaps. Once he had finished this first model, he wanted me to do the outline again. I said that I was sure that he could do it. He refused and I said that if he tried thirty times and still couldn't make it work then I would help him. He agreed. After about seven tries he shouted, "I did it!' He looked so happy with himself.

Two of the regular boys were working on pictures- they decided to try to use the pen as though it were a paint brush and made 2D pictures. They were laughing and joking at how peculiar and odd they looked but, in the end, they said they couldn't believe how well they turned out.

The girls were making pots for their pens. When one girl was finished, she tried to use it but realised that the pot wasn't heavy enough so she designed a gap in the base where she could store her rubbers and sharpeners which she thought would make it heavy enough. When she tried, it worked. She showed everyone in the room hat the idea worked. When the Mum arrived, she proudly showed her too.

Name	102
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the regular session at Currie High School.

Three boys arrived at the session and were talking about it being Robert Burns day the previous day. They told me they had haggis for dinner and learned a poem at school. These three boys each made mini saltire flags. One of the boys wanted to make a saltire flag for everyone. He worked really hard to make them all look good and then wrote everyone's initials on the back of their saltire.

The girl in the group made a tiny little umbrella. She brought one of the cocktail umbrellas with her and copied it with the pens. It looked very sweet and she was delighted with it. She twirled it between her fingers making it look like all the colours were blurred. She then made little 2D umbrellas and connected them altogether. I told her that I had some keyrings with me- she looked really excited and said that she loved that it would be a real keyring. She spent the rest of the session making little charms for the keyring.

One of the boys was making superheroes like the ones he was making last year. He left the hole in his head again so that he could put a drawing pin through it and attach it to the wall. I commented on how neat one of them was and he gave me a big smile and said he felt like he was getting much better.

Name	103
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the first session back at the private school in Edinburgh after the Christmas break. It was a group of brand-new kids who had never used the pens before.

I did a demonstration of the 3D printer and explained how the pens work. The kids were really interested in the printer but a few of them thought that whatever they made with the pen went into the 3D printer to be finished off.

We didn't have long to spend practicing with the pens after the demonstration, so each child chose a template and got a little bit of plastic. I suggested that they just doodle and "make spaghetti" so they could get a feel for how to plastic comes out. This was well received, and the kids laughed when they made big squiggles. Some of the kids wanted to make big long lines and one child told them off and said they were wasting it. I said that it was okay to play and as long- as they were learning it wasn't wasting it.

One girl started leaning hard with the pen and ended up making lots of little flowers. She gave one to me and the other teacher who was in the room. She was delighted to have made something to take home. When her Mum arrived to pick her up, she ran over to her and showed her the flowers while saying "Look!" It was really lovely.

Name	104
Boys	8
Girls	0
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular 3D printing session at the local pottery studio.

It was a busy session with just boys attending. Pokémon has become very popular again. All of the boys made a Pokémon character. They made little stands for them and created scenes using them. One of the boys used the iPad to take photos of the different compositions.

Another boy made a 3D pokeball. He created two empty half spheres. He then added a kind of hinge so that the ball could be opened. He was so pleased with how it looked and after I told him how impressed I was he smiled and showed everyone else what he had made. Everyone was amazed and three boys said they were going to make their own.

The boy who made the first Pokémon started making little mini Pokémon's that he could fit inside his Pokeball. I commented that it was amazing, and that the Pokémon's would look amazing all stored inside the ball. He said that he loved it and was so glad he had persevered with the pen.

At the end of the session one boy searched through Thingiverse and found a Pokémon Go launcher. It is a plastic frame that can be attached to a phone and used as a guide for launching the pokeballs. The boy asked for one to be made in time for the next again week.

Name	105
Boys	6
Girls	1
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the regular session at Currie High School.

There was a new boy who came along today- his Mum had called me to tell me that he had some behavioural problems. Knowing this in advance I decided to make sure that I gave him a lot of attention in the beginning to ensure that he felt supported and capable. When he arrived, I made a fuss of him and encouraged him to pick a picture. He chose an elephant. I showed him how to load the pen and got him to show me how he would use the pen. He wasn't quite leaning hard enough so I placed my hand on the top of the pen to show him the pressure that was required. I let him draw for a few seconds before saying that I was going to let go so to remember to keep leaning hard. When I let go, he stopped leaning hard and the drawing bumped up. He quickly corrected it by leaning hard again and this seemed to make him get the knack. After that he was using the pen really well and was almost silent for the whole session as he worked on his pictures. When his Mum came to pick him up, he couldn't wait to show her all the pictures he had made. His Mum spoke to me afterwards and said she was looking through the window in the door and couldn't believe how calm and focussed he was.

The girl in the group was making little figures on stand for a stop motion animation project she was working on in school. She made two and showed me how she was going to move them. She had attached "sticks" to the side of the figures so she could easily adjust the position. I showed her the translucent filament that we have and suggested she use that for the "sticks", so it was less obvious in the video clips. She looked amazed and agreed- she said quietly under her breath, "this is going to look amazing!"

Name	106
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the second session with this new group at the private school in Edinburgh.

The group were still having some trouble getting their drawings to stick to the paper. I told them not to worry about being messy this week and to just keep practicing. For those who were getting annoyed I suggested that they draw lines with the pens. Once they had drawn a few lines they were starting to get the hang of it. It seems that when they are just doing lines that is the only movement they are trying and so they quickly get through different techniques until they find one that starts to work.

There was one boy who was getting really upset. He was crying and saying that he couldn't do it. I sat with him and showed him the pressure necessary to make the plastic stick. He seemed to feel a bit better, so I went to help someone else. After a few minutes he shouted that he had managed it! I looked over and saw that he had managed to draw a shape. Within a few seconds he was sobbing because he had broken the shape. I went over to help him and reassured him that he was doing really well. I told him that the beauty of 3D printing is that nothing is ever permanently broken. I asked him what the beauty of 3D printing is, and he said, "it can always be fixed". He tried again and when it broke, he started to cry and I said, "but what do we know about 3D printing?" He stopped crying and said, "It can always be fixed!" So, I helped him put a blob between the broken strands of plastic so that they were stuck back together. He laughed and said he's got it now.

Name	107
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular session at the local pottery studio.

I printed the Pokémon go launcher for the boy who had asked last week. When he had it, everyone wanted one. I suggested that they try making their own one with the 3D printing pen as it was quite a simple design.

They started by measuring their phones to make sure their launcher fitted on their phone. The drew out the flat design on paper and then connect it at the sides. A few of the boys did it quickly but their launchers were a bit flimsy. They made another one and made it a lot sturdier and were so pleased with how it looked.

The boy who had his launcher 3D printed on the printer decided that he'd rather make his own with the pen once he saw everyone else's. He chose his colours and made it really colourful. All the boys were really happy with their launchers. They were talking about what else they could make to use in the game.

When the parents arrived to pick them up one of the boys said "we all made something really cool today" they then all lifted up their launchers. One of the Dad's said that they should start a business making and selling them. The boys started excitedly chatting about how realistic that could be. They were all really excited at the prospect and two boys said they wished they could stay and get started on making more launchers.

Name	108
Boys	5
Girls	0
Type	3D printing club
Cost	PPP
Age	6-10

Description

This was the regular session at Currie High School.

It was quite quiet today, so I was able to sit with boys and join in. It is nice when I get to do this as the boys chat more openly to me when I am doing it too.

I was making a cube, just practicing drawing in the air. The boy next to me started also making a cube but then decided that it was going to be a 3D car with moving wheels. He told me that he loves racing cars and that he wants to own a Tesla when he is older. I asked him about the Tesla, and he went into great detail about its specifications- this prompted two other boys to join in and start telling me about their favourite cars.

When the boy was finished the body of the car, he asked me what the best way would be to get the wheels to turn. I was about to describe how I would do it when the other boys joined in and explained how they would do it. They all had different ideas and responded to each other's ideas with excitement. Eventually all the boys stopped what they were working on and began making their own cars with moving wheels. I said that they were all amazing and I was so impressed with their ideas and the way they were working through the process. They all smiled, one boy said, "This is the best club ever, everyone just wants to help each other, and I feel like I can talk without being made fun of."

Name	109
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was a regular session at the private school in Edinburgh.

After crying a lot last week, the boy came in with lots of confidence. He said, "I am going to be amazing at 3D printing today because any mistakes I make can be fixed." I smiled and said he was right. He gave me a huge smile. He was quiet for almost the whole session as the worked on a big 3D printed spider. He showed me it near the end of the session and said the texture was intentional as it was a hairy spider. I said that it was amazing, and he laughed and said, "I know- I'm so good at this!"

Two of the girls decided to make rings. They started off by drawing circles but were disappointed that they kept getting the size wrong. I put a glove on and wound the plastic round my finger. When I pulled the ring off, I showed them how big the circle was- they were amazed that it was much bigger than they thought. They both proceeded to make rings the exact same way. I reminded them that the plastic was very hot, even though the glove and they said they would be careful. One girl started incorporating other colours into the ring and when I went over a while later, I said I couldn't believe how good the rings were. They both smiled and said they loved them. One of the girls made one for me.

One boy was staring at the 3D printer and watching the layers build up on the toy soldier that was being printed. He then took his pen and tried to replicate exactly what the printer was doing. I said that he was making a great job of it and he told me he finally understood how the printer worked.

Name	110
Boys	7
Girls	0
Type	3D printing club
Cost	PPP
Age	9-11

Description

This was the regular session at the local pottery studio.

The boys were less excited about the launcher this week but two of them still wanted to make more that they could maybe sell. These two decided that the launchers should all look the same so one of them drew the design out on paper and the other one traced it so that they would be the same. I reminded them that the launchers would have to fit different phones. One boy took the measurements from everyone's phone in the room to try and get a good variety of sizes. They boys spent the whole session making launchers. They made some multi-coloured ones, some with spotty patterns on them and other that were just one colour. I took a photo of all the launchers and the boys were so happy- the were smiling and one of them said "we've made so many- people are going to love them!"

The other boys were doodling with the pens as the spoke about the batman Lego movie that had just come out. One of them had brought along some Lego figures and was making tools and weapons for it using the pens.

I told them that we could print some pretend Lego bricks and they were amazed- they all wanted one. We printed just the four stud bricks so that they could all take one home with them. When I handed them out at the end, they were all amazed at the finish and utterly delighted that the Lego man could stand on top of them.

Name	111
Boys	6
Girls	0
Type	3D printing club
Cost	PPP
Age	6-11

Description

This was the regular session at Currie high school.

Today was really quiet again. Three of the boys are really into Pokémon Go at the moment. I showed them a photo of the launchers that the other boys made. The three boys decided they would make them too. None of these boys have their own phones so they borrowed their Mum's to get the measurements. One of the boys made one that was really sturdy and fitted perfectly. He lifts it up and looked so proud when he tried it out. The other boys commented that his was great. He gave them tips on how to make theirs equally as good. They seemed really happy with the help.

Two of the other boys had brought toy cars with them. They said they wanted to make a bridge that the cars could drive over. I suggested that the start with the pillars under the bridge and then add the road. They said they wanted cables on it too so that it looked like the fourth road bridge. They told me that they had walked over it the previous weekend.
They worked really well together and made the bridge work. They realised that the road needed to be thicker than they had initially designed it as the cars were relatively heavy. When their Mum came to collect them, they were so excited to show her. She said it was amazing and they looked delighted. They then detailed which parts they were responsible for.

One of the other boys was making a little figure. He added a short bit of filament through the top of the legs so that the legs could move freely along the "hinge".

Name	112
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

The boy who was really interested and focused on copying the 3D printer last time started using the same method as the previous week. He tried to keep up with the printer as it completed each layer. He asked me why his looked messier than the printer. I explained that the printer has a smaller nozzle, so the layers are thinner while means that the model is more detailed. He said he understood but looked a bit frustrated. He then practiced at drawing really thin lines by reducing the speed at which the plastic was extruded from the pen. At this speed he was unable to keep up with the printer, so he started just trying to make a really neat cylinder and told me he was just practicing now.

The girls who were making the rings last week made more rings this week. They decided to make necklaces too and thought they could draw around their necks! I told them they couldn't do that as the pens were too hot. Instead they drew big circles that would fit over their heads and then added little squiggles onto the necklace acting as the pendants.

One of the boys was still struggling to get his pen to work in the way he wanted. I suggested that he practice drawing his name since he already knew how to do that. He kept practicing- I said that if he drew his name thirty times, he would be an expert. He seemed to take this as a challenge and suddenly enjoyed practicing. He finally managed to get his name looking right and he shouted, "Denise! I did it!"

Name	113
Boys	6
Girls	1
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

There was a girl there for the first time in what feels like ages. She saw that the boys were making Pokémon figures and commented that she liked it but didn't know much about it. She took a template of psyduck and drew it in pink filament. One of the boys complained that she was doing it in the wrong colour, but she brushed him off and said that it didn't matter- it was just for fun. He looked annoyed but then started making Squirtle which he hadn't wanted to do before because I only had one shade of green. He used blue and green instead of two shades of green.

Most of the boys were making Pokémon figures and chatting about Pokémon.

One of the boys was using one of the laptops to design a baseplate for his Pokémon figures to sit on top of. He made an oval shape and the wrote "made by [his name]" and extruded the letters. It looked really great. We printed it and when it was finished, he ran through to show his Mum. He said he really liked it. He took one of the figures that he had made last week and sat it on the baseplate and then took a photo of it.

Name	114
Boys	6
Girls	1
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the regular session at Currie High School.

One of the boys came in and was a bit upset. He said that his Gran wasn't well and was in hospital. I asked about it and he told me what had happened and said he was visiting her that evening. I suggested that we make her a gift. He wanted to make it on the 3D printer, so I sat with him and helped her make a love heart that said "Get well soon" like he wanted. He was so happy with it. He watched it the whole time it was printing. When it finished, he held it in his hands and said, "This is sure to make her feel better!"

Another boy heard what had happened and told him that his gran hadn't been well the year before but that she got home quickly and that it was the soup that made her better. He said it was magic soup. I asked what type of soup was magic- he said noodle. He then used his pen to draw noodles and said, "just like these."

The girl who was there today made a tree. She started off not sure what to do but had picked the golden-brown colour and drawn lots of circles, one inside the other. The boy next to her said that it looked like the rings in a tree. He said that is how you can tell what age a tree is. She smiled and said it was a tree and carried on making a 3D tree. When we were at the end, she asked me to help her make a tiny bird to sit in the tree. I helped her and she looked delighted with it and was so pleased that the tree stood up perfectly.

Name	115
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

One of the girls was excited to tell me that she had joined a rainbows group. She told me all about her first night there. I suggested that she could make a rainbow with the 3D printing pen. She loved this idea and went over to the filaments to collect the colours that she needed.

Two of the other girls wanted to make a dice. I showed them the two methods for doing it. They both chose the layering method and one of them said “this is how the 3D printer does it.”

One of the boys wanted to make his own 3D printer. He made a box shape and then draw on it, copying the design of my 3D printer. He joked around and told the other children that he had his very own 3D printer. He was so excited and said that he was going to ask Santa for one.

One of the other boys was a bit distracted and wasn’t making anything in particular. He told me he was tired and hungry. I said that he didn’t need to make anything in particular, so he was just playing about with the pen. He stood up as he was drawing a line up in the air. When he let go it fell down because it was just a little too flimsy. He decided that this was a fishing rod though and happily played for the rest of the session acting as if he really was fishing.

Name	116
Boys	8
Girls	2
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the regular session at currie high school.

The weather is a bit nicer today and the kids had been jumping on the long jump before they came in. Two of the boys made mini sand pits and little figurines. They pretended to be doing the long jump. I said I loved them, and they were amazing. The boys looked thrilled with them.

When one of the girls saw how amazed I was by the mini long jump set up that the boys had made she decided to make me one. When she finished it, she brought it over to me and said that this was for me because this was her favourite class. I thanked her and told her how beautiful it was, and she gave me a big smile.

Three of the other boys were making Pokémon figurines. They chatted about which Pokémon they had caught that week. This led to a very excited conversation about the different Pokémon. One of the boys showed me the app and showed me which pokemon he had collected. I commented on how cool it would be if they actually had shelves in real life showing all the Pokémon they had collected. The boy said, “oh yeah!” before running back to his desk and making a mini shelving unit and adding miniature versions of all the Pokémon characters that he had caught on to it. It looked amazing and one of the other boys said that was a really cool way of showing everyone else what he had caught. The boy said it was his man shelf.

Name	117
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

One of the girls had asked that we print power rangers on the 3D printer. I did that but because I had to scale the model down, so they were a bit stringy and the kids commented that they looked messy. I said, “see even the printer can make messy models.” The kids seemed to really like this and one of them said, “I could do better than that.”

Despite the messiness of the models the kids seemed to like the power ranger figures. One of the girls told me that her favourite was the pink power ranger. She decided to draw one with pink filament.

One boy came in and told me that he had seen a YouTube video of a guy who had made a mask with the 3D printer. He said he wanted to make his own one. I told him that a full-size mask would talk longer than the time we had but that we could try to make one with the pens. He didn’t seem that keen on this idea but agreed to try. I helped him get the outline the right size and the eyes in the right place. He struggled to fill the space in between initially as it was so big but after he realised that he could make a mesh instead of filling every single hole he managed to get into a good rhythm with it. It did take him the whole class but once it was done, he was delighted. He saw his Dad at the door to collect him and said “Look! Dad! I made that mask we saw on YouTube!”

One of the girls made lots of little flowers. She said that she was going to make a bunch of flowers to give to her Mum for being a nice Mum. She seemed to enjoy making the flowers so much that she didn’t bother making any stems for them and instead just made around thirty flowers. I said it looked a bit like pretty confetti and she thought for a second before saying “That’s what it is!”

Name	118
Boys	7
Girls	1
Type	3D printing club
Cost	PPP
Age	8-12

Description

This was the regular session at the local pottery studio.

The weather was really nice outside and the boys were desperate to go outside with the pens. So, we plugged an extension in and sat outside on the patio area with the pens leaning on top of books. The novelty of this caused quite a bit of excitement. Three of the boys picked up stones from the ground and wound plastic around the stones. This created a type of cage around the stone. One of them dropped it and realised that the stone bounced when it was in the plastic cage. This was very exciting for the boys and within minutes they were all making bouncy stones.

The girl who was in the class thought that the view was really pretty. She decided that she would paint a landscape using 3D pen. I commented on how beautiful it looked and she looked so happy. She drew a frame around it so that it looked like a miniature piece of art. She told me she was going to make one for her aunty too.

One of the boys looked through Thingiverse and found a model for gliders. We printed one off and tried it out. The boys loved it, and each took it in turns to throw the mini glider and had a competition to see how far they could throw it.

Name	119
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular 3D printing session at a private school in Edinburgh.

One of the girls was really excited when I came in. She came up to me and told me that she was a big sister. I said that was amazing and asked about her new sibling. She told me that he had been born the day before, but she hadn't met him yet. She said she wanted to make a present for him. She drew a blue love heart and asked me to help her write "I love you [his name]" inside the love heart. I helped her and then we used a piece of ribbon I had in my bag to tie a bow on it so it could be hung up. She thanked me for helping her and had the biggest smile on her face. At the end of the class her Mum came in carrying her brand-new baby brother. She looked so happy and quickly ran to her bag and took out the heart she had made for him and held it out in front of him. It was such a beautiful moment.

Two of the boys were having a playdate after school. They were chatting excitedly about it. They said they were going to play with one of the boy's cars. I suggested that they could make some things for their toy road/race track. They loved this idea and decided that one of them would make mini traffic cones while the other would make a toy racing flag. The laughed and smiled as they were doing it and kept saying "this is so fun!"

One of the other girls was using a template of a teddy bear. The teddy was holding a big heart. She didn't manage to finish it in the time we had but the only unfinished but was the heart. She was a bit annoyed, but I suggested that she use it as a picture frame. She loved this idea and the girl next to her who had also done a teddy but managed to finish it used scissors to cut the heart out of her teddy bear so that she could use it as a photo frame too.

Name	120
Boys	5
Girls	7
Type	3D printing club
Cost	PPP
Age	6-7

Description

This was the regular session at the private school in Edinburgh.

One of the girls told me that she had been at the museum at the weekend and seen something called a zoetrope. She started by taking a piece of paper and gluing one end to the other creating a cylinder. She cut lines in it so you could almost see through it. She then used the 3D printing pen to write the names of everyone in her family and then organised these around a circle. She tried to spin the cylinder around the names. It didn't quite work in the way she expected but it looked really good, nonetheless. She took it around the whole group and showed everyone individually while explaining what a zoetrope is.

Two of the boys were making mini swords to go on their pencils. They each wrote their names along the blade of the sword and then used the pen to wrap the filament around the pencils. They then used the pencils to have a pretend sword fight.

One of the boys drew a big love heart and then asked me to help him write his Mum and Dads names inside it. He told me that it was their anniversary. He looked so happy and said he was so excited to surprise them with this heart.

Name	121
Boys	7
Girls	2
Type	3D printing club
Cost	PPP
Age	6-12

Description

This was the last session at currie high school before the Easter break.

The girls came in and said they wanted to make an Easter basket to collect their eggs in. I said that they were a little limited on time to make something really big so to maybe make a basket that could hold small chocolate eggs. They looked excited. One of the decided to draw the basket by drawing layers one on top of the other. The other girls made a grid like shape by drawing in the air. I said that they were both doing great and had come up with interesting ideas of how to make their basket. They looked so happy. One of them called me over at the end to ask how they should make the handle. I did a demonstration to show them and they both said "aww" at the same time and quickly made one each and attached it to their basket. They were so happy with the final basket.

One of the boys had chosen an egg design from Thingiverse. It was printed in three parts. Two half eggs split horizontally and a threaded cylinder which connected the two halves together. When the boy saw the final print, he was so happy with it. He said, "it's the best egg I've ever had- it's perfect." He then made little balls to go inside it. When he shook it, it rattled. He laughed and smiled.

Two of the boys were making a mini bow and arrow. They used rubber bands for the string. At the end they wanted to have a competition in front of their Mum's to show them how well they worked. They seemed to love performing and showing off what they had made.

122

5

7

3D printing club

PPP

6-7

This was the last session at the private school in Edinburgh before the Easter break.

The kids were quite excited. A few of them told me about where they were going on holiday. One of them was going skiing- she told us that she goes every holiday and loves skiing. She told me she gets hot chocolate. She then started to draw a mug with hot chocolate in it. This prompted a girl sitting next to her to make a 3D cup. She was desperate to find out if it would contain water without leaking. She realised she wouldn't have enough time to make a full size one so she made a tiny little one that she said could be for her doll. When she was finished, she ran over to the tap and filled it with water. The water leaked through a little bit, but she was thrilled. She said, "I can't believe I actually made something real."

Four of the boys chose some Easter themed templates. They draw the shape of an egg and decorated it. They were chatting excitedly about how they paint their hard-boiled eggs and roll them down hills.

One girl made a big sunshine. She said she wanted to make it really big so that the weather would be nice over the holidays. I commented that that was a nice idea and she giggled and said it was silly.

When the parents arrived one of the Mums came in to thank me. She said that her son had loved this classes and that he was so proud of everything he had made.

Name	123
Boys	10
Girls	14
Type	Youth club
Cost	O
Age	9-14

Description

This session was booked by West Lothian council for a youth club in Bathgate partnership centre. It was a large group of 26 participants. As it was a large group, I split them into teams to do the egg challenge.

At the beginning of the session I demonstrated how the 3D printer worked. We then had a discussion about 3D printing. One boy asked if we could print a gun. I explained that it was possible but that the files were not easily accessible because it would be dangerous if anyone of any age could have unrestricted access to a weapon like this.

We then spoke about using 3D printing for positive applications, especially so that it doesn't become associated with negative stories and then never be allowed to reach its potential.

When the young people got started it seemed that in each group of 4 there was one person who had the knack of using the 3D printing pens and the rest struggled demonstrating his by saying "it doesn't work!" So, I suggested that everyone make their names first so that they got used to using the pen and the speed at which the plastic comes out.

After this everyone seemed more confident in using it. Each team created an egg protector and then we dropped the eggs from a height. One egg splatted on the floor.

As I was tidying up one girl carried on using the pen and she told me she was making everyone in her family a present.

Name	124
Boys	10
Girls	14
Type	Youth club
Cost	O
Age	9-12years

Description

This session was booked by West Lothian council for their intermediate youth club.

It was a large session with 24 children in it. Again, I did a 3D printer demo and then split them into teams. This group seemed more competitive than the one this afternoon. The boys were using their water bottles and other things they could find to make their towers higher.

One group of girls realised that the translucent filament looks a little like crystals if they let the plastic bubble out of the pen in a particular way. They then did this constantly to make things that they could stick onto the side of their towers such as hearts, flowers and spirals.

There was a snack time and during this they got to play outside or in the hall. Some girls and one boy stayed to make some different things with the pens. The boy made an eyeball logo from a YouTube channel. The girls made some superheroes including superman, batman and ironman.

Name	125
Boys	16
Girls	14
Type	Youth club
Cost	O
Age	7-9years

Description

This session was booked by West Lothian Council for their young youth club.

It was a massive session of 30 children under the age of 10 so there were many challenges.

I did a demonstration of the printer and tried to have a discussion with the kids, but the youth workers shouted at any kids who tried to talk and so almost all of them looked too scared to talk. I split them into 6 groups to create the tallest tower that a marshmallow could sit on top of.

Within the groups the kids were smiling and laughing and all working hard to make the pens work in the way that they wanted it to. Whenever one of the leading youth workers got involved though they were told off for "messing about". I tried to defend them and explain that they were experimenting, and this is how you learn to get the knack of it. They dismissed this suggestion and said I just didn't know what they were really like.

At the end when it was time to measure the towers each group proudly presented their tower. Lots of them commented that the pens were so much fun but not easy to use until you practiced.

Name	126
Boys	2
Girls	4
Type	Youth club
Cost	O
Age	13-16

Description

This session was booked by West Lothian Council for the senior youth club in Whitburn.

It was a very small group and all of them had volunteered at one of the other youth clubs that I have delivered this week. They wanted to choose something to print and they opted for some stormtrooper heads from Star Wars.

As it was such a small group we just sat around a table and used the pens. Most of the young people started by using the letter templates to make 3D names. As they were doing this one of them asked me what the coolest thing I'd ever made was. I said I enjoyed making little robots. One of the girls asked if you could make things like shoes. I said I hadn't tried but I would start. So, I drew around my foot and started making a shoe. This seemed to entertain them, they smiled and started talking about other 'crazy' things they could make.

One of the leaders commented that they had never had such a quiet group as this, and everyone was so focused.

Name	127
Boys	16
Girls	14
Type	Youth club
Cost	O
Age	10-13

Description

This session was booked by West Lothian council for their Bathgate youth club. I set it up the same way I did for last week. I gave a 3D printer demonstration and printed some Ultimaker robots as prizes for the marshmallow tower challenge.

A boy asked about printing guns and one of the girls told him off and said, “why would you want to print guns when you can print things that can save lives instead of ruining them?” The boy mumbled that it was just for playing with.

It was another large group, so I split them into six groups of five. This week the object was to build towers that could support a marshmallow on top. Some children had done this the previous week, so they got started straight away.

For the children who hadn’t done it they struggled a little and got frustrated, especially when they could see the children who had already done it being able to easily draw. I explained that it just took practice and with each child who was getting particularly disheartened, I placed my hand on top of their pen and told them to direct it. This allowed me to show them the pressure that is necessary to make the plastic stick to the paper. As I was about to let go, I told them that when that when I let go, they would have to keep that pressure.

This certainly helped and every child smiled as they got it working and most of them said, ‘ah, I get it.’

Name	128
Boys	11
Girls	14
Type	Youth club
Cost	O
Age	9-12

Description

This session was booked by West Lothian council for their intermediate youth group at Whitburn community centre.

It was another big group, so I did a demonstration of the printer and split them into groups, this time we did a ‘protect the egg’ challenge and this time I boiled the egg first!

The groups were really competitive and there were at least one in each group who wasn’t that into the 3D printing aspect and were more interested in beating the other groups. The young people also tended to wind people up which made the session quite volatile.

Every group opted for trying to wrap the egg up with the pen, almost like weaving. However, only one group didn’t get bored of this and this technique turned out to work well.

At least one in every group was really interested in how the 3D printer works and explained ideas they had and asked if they would work. These ideas including printing inside a solid paper blog, making new organs that didn’t yet exist and making a table.

Name	129
Boys	10
Girls	20
Type	Youth club
Cost	O
Age	9-15

Description

This session was booked by West Lothian Council for the Armadale youth club. It was a very busy session. The youth club itself was in a different building which was a 5-minute walk away. I was allocated a room in the community library as it was easier to access with my equipment.

As it was such a large group, I split them up into teams and challenged them to build the tallest tower. This activity worked particularly well with this group, perhaps because they were a little older and spent a lot of the youth club sitting chatting. This activity allowed them to continue to do this while working on something productive.

One boy in particular was fascinated by the ability to draw in the air. He kept practicing until she worked it out. After he got the hang of it lots of the other young people asked him to teach them.

Alongside the tower some people made some glasses and other made names for their friends and families.

Name	130
Boys	3
Girls	10
Type	Youth club
Cost	O
Age	15-18

Description

This is the first session that I have done at this youth centre. The citadel is a type of community centre- not council run, which has youth clubs for all age groups, activity groups for young mums and other services for young people and their families in Leith.

This group was quite different from other groups I have done. The young people could be quite challenging- literally.

They were quite defensive and quick to anger and respond. It was rowdy and discussions often when into inappropriate areas.

I gave a brief demo of the printer and then responded to questions and thoughts as they arose.

The art room, where I was, was one of many activities available.

A few of the girls and boys made inappropriate body parts. However, some did make things more typical of a group's first shot of 3D printing including flowers and hearts.

Name	131
Boys	12
Girls	8
Type	Youth club
Cost	O
Age	7-9

Description

This session was booked by a youth agency in Wester Hailes. As it was a group of younger children and I had been booked for 2hours I decided to split the group in two and give each group one hour.

I started each group off with a printer demonstration. We spoke about what they would print if they could make anything. Some of the suggestions included a rocket, shoes, a house and a puppy. We spoke about the feasibility of these ideas and I showed them a photo of the shoe I made.

Some of the children got quite frustrated when they could get things working. Two of them cried and said they had burnt themselves. After checking them over I realised that they were just worked up and weren't hurt so I gave them a little more support. A few children got the knack quite quickly and made some fun pictures. One of them made a crocodile which looked great and they were so happy with it and went around showing everyone.

By the end of the session, all the kids were happy and as the parents came in, I heard lots of children excitedly explain what they did and how a 3D printer works.

Name	132
Boys	21
Girls	19
Type	Youth club
Cost	O
Age	7-9

Description

This was a session booked by the citadel youth centre for their junior youth group. I was not prepared for how busy and challenging it was going to be. When I arrived, I was placed in the art room. They asked how I'd like to run it and I said considering the age group and the fact that there were other activities on that I would like a maximum of 10 at any one time. The prepared a sign-up sheet and put it on the door and then locked me in so that the kids wouldn't come rushing in. The kids weren't allowed in until the exact time it started.

Despite the controlled manner in which it was organised it was still a lot to deal with. I had a volunteer allocated to me too. I demonstrated the 3D printer and then showed them the pens. Most of the kids were very demanding and quite stubborn. Unlike most groups I have worked with so far, they weren't trying to get me to like them and instead I felt like I was proving myself to them. In the end, despite the difficulties it was a very rewarding session. It meant a lot when the kids understood what they were doing and said 'yay' when the managed to do it. It seemed that they were really proud of themselves.

Name	133
Boys	18
Girls	22
Type	Youth club
Cost	O
Age	10-13

Description

This is probably the most challenging group I have ever worked with. There were 40 young people signed in and there were so many fights that broke out that I lost count. Young people were thrown out, the police were called and at one point the room I was in was locked to contain a boy who lost control. It was quite a frightening experience. However, it did let me see and extreme version of groups which made the observations even more obvious.

For example, it was mainly girls who took part initially. The one girl convinced her boyfriend to come through with her. He had a shot of the 3D printing pens and became really focussed and stopped pestering her to kiss him. Some of his friends came through to get him to go and play a game and he told them to have a shot of the 3D printing pens and one of them said no because it was the girl's room (referring to the art room). The other boy said it was really good, so they too became quieter and focused. One of them said he was going to make a heart for his gran which seemed quite out of character for this boy at least in this context.

Name	134
Boys	12
Girls	18
Type	Youth club
Cost	O
Age	6-12

Description

This session was booked for a Summer holiday programme. It is a low-cost children's group subsidised by the council. I arrived and all the kids were out playing on the grassy area out front. I was told to set up in the cellar room- it looked like the inside of a dungeon in a castle.

All the kids came in. I did a demo of the 3D printer to everyone and then let them use the 3D printing pens. Most of the boys left to go out and play football so it was mostly girls and the younger boys who were left. Several of the girls made unicorns. They struggled a little to get the plastic to stick initially. I encouraged them to keep going and they all eventually got the knack. They looked pleased when they made something then lifted it up and said, "look what I made". Then when someone else saw what one of the girls had made, she said, "oh I can't do it" and the girl went over to help her and showed her the pressure that was needed.

Towards the last half hour some boys came in shyly and used the pens and watched the printer.

Name	135
Boys	0
Girls	14
Type	Youth club
Cost	O
Age	9-13

Description

This was session for a girl's youth group.

I set up in the art room and did a demonstration of the printer before showing the girls how to use the 3D printing pens. A few of the girls had attended sessions before so were keen to get started.

The youth workers were really into using the pens too and one booked me for her own 40^{th} birthday party.

Most of the girls started out by making love hearts. One girl made a little memorial thing to take to her Dad's grave. She made it heart shaped and then added her Dad's name and drew a trophy on it which said Hibs.

One girl was struggling to get the pen working the way she wanted and got annoyed when the plastic kept peeling up from the paper. I showed her a different way to fill in the shape. This was achieved by melting the pen into the outline, quickly pulling the pen over and melting it into the other side. This led to a stringy fill effect which looked good.

After I'd demonstrated this to one girl everyone else started doing the same thing. A lot of the girls were in a dance group and they started to make love hearts with their dance groups name in it.

Two of the younger girls made names for everyone in their family.

Name	136
Boys	12
Girls	4
Type	Youth club
Cost	O
Age	14-17

Description

This was a workshop run for a youth group for seniors.

This youth centre has several rooms with different activities in each. I was allocated the art room. I set up the 3D printer and 3D printing pens.

As the young people came most of them popped their head around the door to see what was happening in the art room. A few of the boys came right in to look at the 3D printer- the chatted briefly about it being cool.

A bit later the boys came back with some of their friends. I gave them a brief demonstration of the pens and chatted them through the 3D printer. They wanted to print some little figures on the printer. They each used a pen- to start with they were having a bit of a carry on and making inappropriate things. I didn't acknowledge what they were making but gave instruction on how to get a better result. Once they realised that I wasn't going to be shocked or tell them off they took it a bit more seriously and most of them sat in silence for at least 15 mins as they doodled with the pens.

Some girls came in to see the boys and weren't interested in the printer or pens at all until one of the boys told a girl to have a shot of his pen. Once she had tried the pen, she asked for her own one and the girls joined in. The girls all made love hearts with their names in them. They started to make things for the boys too but after a few joke comments they stopped, and they all went through to the kitchen for food.

Some other boys came through and sat quietly making some game pieces for their games. They were really quiet apart from one boy who talked a lot about the board game they were playing. At the end they all gathered everything they had made including the initial messy ones and took them home with them.

Name	137
Boys	24
Girls	6
Type	Youth club
Cost	O
Age	7-9

Description

This was a workshop for a youth club for primary school aged kids living in Leith.

It was a very busy workshop and kids were in and out constantly.

I insisted that age group wore gloves to protect their hands. The room was small for the number of kids in it and people weren't sitting quietly or carefully for a lot of the time which made burns more likely.

There was a little girl who was identified to me as having some social behavioural issues. She demanded a lot of attention and when she was unable to make the pen work the way she wanted she screamed and shouted. I reminded her how to do it and reassured her that it takes practice. After a lot of frustration, she managed to make a rainbow and she was delighted with it. She said that she couldn't believe that she had managed it. She said she couldn't wait to show her Mum.

There were three boys who were having a bit of a carry on and getting into arguments. They picked the pens up and tried to burn each other with them. I sternly reminded them that these were dangerous, and they could get seriously hurt. I got one boy to show me him using the pen and when I praised him for doing it so well, he looked at me with the biggest smile on his face. The other two boys looked at each other as though they weren't sure whether to make fun of him but they both picked up their pens and tried. They became silent as they worked on their drawings.

Despite this workshop being chaotic and it being difficult to run it in the way I normally would I feel that the quick moments that I worked with individual children were extremely productive and made a different to how they children saw themselves.

Name	138
Boys	0
Girls	11
Type	Youth club
Cost	O
Age	10-17

Description

This workshop was for a youth club for girls in the Leith area.

This group was varied in terms of how the girls responded to the activity.

The younger ones treated it like any other craft and compared the activity to doing hamma beads. They focussed for most of the time on their projects- most of them made love hearts with their name and/or their boyfriends names inside them.

The older ones were less inclined to join in initially. Instead they sat around the table and gossiped about what had been happening and mocked the girls who were making things. One of the girls asked if it was possible to make something inappropriate. I said that was fine—she could make whatever she wanted. She did and after everyone laughed a bit, she commented that it was really fun and started writing her name in nice handwriting. This prompted the other older girls to join in too.

As the girls chatted the conversation drifted into some problematic areas. The staff who were in the room joined in and were able to offer suggestions and signpost services that the girls could access.

At the end of the session the staff spoke to me and said that they were surprised how quickly the girls started talking about some problems they were having in front of me. They said they loved the pens and were amazed at how well received they had been.

Name	139
Boys	14
Girls	10
Type	Youth club
Cost	O
Age	9-12

Description

This was workshop run for a youth club intermediate group. This is for pre-adolescent kids.

This was the most difficult and challenging workshop I have ever run. There were fights, a lot of anger and a lot of kids running in and around the room.

I set the printer up on the counter at the side while the 3D printing pens were laid out on the table. The first group came in and were rowdy, disinterested and not listening to me at all. Eventually I decided that I would just sit at the table with them and use a pen in front of them.

After a while they started watching what I was doing, and a couple of kids started to copy me. Once they had made something the rest were interested too. It was tricky to make the kids realise that it takes practice to make the pens work the way they wanted. They got frustrated and threw the pens. I went around each of the kids individually and showed them the pressure that was necessary to make the plastic stick to the paper. A few of them got the hand of it quickly.

One of the girls made a rose and when she had finished it, she held it up and said "Look! It worked."

One of the boys was getting really frustrated and I couldn't seem to get him to believe me that he was doing well. One of the pens had jammed earlier so I gave him a screw driver and asked him to open the pen up. Once he had it open, I showed him how to unjam it. He was delighted with himself that he had fixed it. He spent the rest of the night asking if there were any pens that he could fix.

Name	140
Boys	8
Girls	3
Type	Youth club
Cost	O
Age	10-17

Description

This was a special session for the intergenerational group at the citadel youth club.

The young people were encouraged by the youth workers to bring an older person into the art room which a few managed to do. Most of the young people had already taken part in a session with me so were familiar with using the 3D printing pens.

Those who had managed to bring an older person through sat with them and showed them how the pen worked. One of the older people said they would just watch as they weren't very good with technology. The young person said that was silly and reassured them they could do it, so the older person had a shot and seemed to enjoy it- laughing as the plastic became stringy.

Another intergenerational pair were working together to make a Hibs badge. The younger person was operating the pen while the older person instructed them what part should go where and where the writing was on the badge.

One of the older ladies wanted to make little name plates for all of her grandchildren. She asked one of the younger people for help and they ended up chatting about her family and his family.

Name	141
Boys	6
Girls	0
Type	Youth club
Cost	O
Age	14-17

Description

This was a workshop for a games club based in Leith.

This was a very quiet workshop with boys who tend to be a bit quieter. I was based in the art room while there were games consoles and computers in two other rooms.

Initially it was difficult to get the boys to come through- they were all happily playing their games. Eventually one of the boys who had been at a group on a previous night came through and wanted to make a character from a game he was playing. He was quiet but after I started talking to him about the game he was playing (I was also sitting using the 3D printing pen) he started chatting a lot and seemed a lot more comfortable.

A boy looked into the room and when he heard the conversation he came in, sat down and joined in. I wasn't sure that he would actively join in with the printing as he had said no earlier when the group leader asked him. So instead of asking I picked up a pen, showed him how it worked silently, just pointing to the buttons and lights as we spoke about the game. He instinctively chose a colour when I held them up in front of him. I fed the colour into the pen and when it was ready to use, I handed the pen to him. He started drawing with it and then the room became silent as both boys were really focussed on their models.

Both boys made figures from the game- both were quite critical of themselves but when I said how well they had done they both seemed happy with themselves. When some other boys came in later one boy held up his figure and said, "look what I made!".

Name	142
Boys	34
Girls	23
Type	Youth club
Cost	O
Age	7-10

Description

This was a workshop for a youth club based on the outskirts of Edinburgh.

This is an extremely busy youth club with lots of activities on offer. I was based in the unused changing rooms. This is where kids come to hang their coats up. Because of this all the kids saw what we were doing, and everyone wanted to join in.

I did a demonstration of the 3D printer and then asked if anyone had any questions. The first group were intrigued by the idea that you could 3D print and 3D printer.

There were four boys sitting together, they wanted to make weapons to toy fight with. I didn't stop them doing this but encouraged them to consider the design aspect instead of just being fixated on what harm could be down with a real-life version.

There were two girls who were make a friendship bracelet. They started by making a single line drawn but it was breaking quite easily. I suggested that they make a chain by connecting links. They loved this and were so pleased with the outcome. When they left the room, they were wearing the friendship bracelets.

One boy was really good at getting a neat line with the pen and everyone at table was watching him. He loved the attention and tried to explain exactly how he was managing to get the line quality.

Name	143
Boys	31
Girls	28
Type	Youth club
Cost	O
Age	11-15

Description

This was a workshop for a youth club for high school pupils based in a village just on the outskirts of Edinburgh.

I was based in room in the community centre but there were lots of other activities on offer.

Five boys came by initially. They were intrigued by the 3D printer and wanted to know exactly how it works. I explained and showed them some examples of things I had 3D printed including a fidget spinner. This was very well received. I suggested that each of the boys make their own one with one of the 3D printing pens. They sat down and I showed them. They looked amazed and all started making their own ones. When other kids saw what they were making they all wanted one too. I ended up with a queue of kids waiting for their shot.

A girl was struggling to get the cylindrical part to attach to the finger pad. I offered to help but she didn't want my help, she wanted to do it herself. I reassured her that she was doing great and described in detail how to make it work. She kept treating the plastic as though it was glue. When she realised that this doesn't work, she got the hang of it. She shouted me over to show her when she was done. She said "I can't believe I got it working! Can I make one for my brother?" I said she could, and she ran over to choose her colours.

One boy finished making his fidget spinner and then asked when he could put it in the 3D printer. He thought that the printer made the drawings more solid.

Name	144
Boys	9
Girls	6
Type	Youth club
Cost	O
Age	7-10

Description

This was a workshop for a youth club for primary school children based in West Lothian.

I did a demonstration of the 3D printer before showing the kids how to use the pens. Several of them said “ooooooh” as I drew in the air with the pen. They were so interested in making it work. Initially they were a bit frustrated by the messiness of the pens but after some practice and feeling the pressure necessary they got the hang of it.

One girl made her name. She said “I did it! It’s so beautiful. I am going to make one for everyone in my family.” She went on to write at least twenty names out in fancy writing. She was so pleased with them and wanted me to take a photo of all the names.

Two of the boys started playing knots and crosses with the pens. They were just having a bit of a carry on but ended up taking pride in how their move came out.

A girl was using blue filament and one of the boys said that she was a boy because she liked blue. The girl didn’t say anything but two of the girls said, “So what if she is?!” I commented that blue isn’t a boy’s colour anyway and that lots of girls like blue too. The girls agreed and said “see!” I don’t normally get involved but in this case, I felt like the girl would benefit from some reassurance.

Name	145
Boys	10
Girls	9
Type	Youth club
Cost	O
Age	7-10

Description

This was the second workshop I had run for the primary school aged youth group in West Lothian.

Last week the kids had been learning to use the pen and this time they had come full of ideas. They wanted to do Disney themed drawings.

Two of the girls were making Minnie Mouse plaques. Once they were finished, I suggested that they add their names to it and that they could hand it up on their bedroom door. They loved that idea and immediately started to choose a colour for it.

The boys were doodling a little and not making anything in particular. I reminded them how to draw in the air with the plastic and they looked really excited. One boy said that he was going to make a cube. One of the other ones decided he'd make a dice as the dice were missing from the games in the club.

One girl wanted to make a get well soon card for her gran who was in hospital. I thought she meant she wanted to make something to glue to the front of a card, but she actually wanted to make a whole card with the pen. She spent a long time on it, but it wasn't finished by the time the session ended. She asked if I would keep it until next week. I said I would, and she looked so happy before saying she loved 3D printing. She said, "I feel like I can do anything!"

Name	146
Boys	9
Girls	8
Type	Youth club
Cost	O
Age	7-10

Description

This was my third session at the primary school aged youth club.

The girl who was making a get well soon card for her Gran was jumping up and down excited to get started back on her card when I arrived. I gave it to her, and she got to work immediately.

The boys decided to have tower building challenge with the pens. One of them started talking about how a triangle is the strongest shape to build a tower from. One boy used a triangle for the base and drew up from the three points. Another boy decided to make lots of triangle outlines. He told me that he planned on attaching the triangles to each other and making a tall structure that way. By the end of the session two of the boys had made towers that were really tall. The one made from individual triangles was very impressive looking but was not very high as he had made a more spread out composition. The other one had lots of supports drawn from the paper up to the top of the tower. He was really happy and described in detail how he had managed to get the tower to stand up by adding the supports. I told him that he had done amazingly well, and he looked so happy.

The other girls were making lots of different models including a rainbow, Mike from Monsters Inc. and a lot of hearts. One girl said that she wished they could do this every week as they had loved having the 3D printer there. I reminded them that I would be there the following week, and everyone said “yay!”

The girl finally finished her card and it looked amazing. Everyone commented on how lovely it was and said her Gran would be so pleased. She smiled a huge smile and said “I really worked hard on this. I don’t think I’ve ever tried so hard at anything before. I love this!”

Name	147
Boys	11
Girls	8
Type	Youth club
Cost	O
Age	7-10

Description

This was my fourth and final session at the youth club for primary school aged children in west Lothian.

There were a couple more boys this week and the ones who made towers last week challenged the others to make towers as good as theirs. The girls wanted to join in too. Three of them worked in a team.

One team of girls split the task into three parts, drawing a long pole and making a base between two of them. They decided to attach the parts together to make it really strong. When it balanced, they jumped up and down and said “Yay!!!”

The boys worked individually, and each had their own technique. One of the boys broke his tower by mistake just before the end and one of the others said he could join him. It was really nice.

I had taken a measuring tape with me to measure the towers in case they did the same thing this week. Just before the end everyone presented their towers and I measured them. I commented on how well designed one of them was and how nicely the colours worked together. The girls looked so pleased and other kids joined in with complimenting it. One of the boys one the challenge and he said he was so pleased because he had really been practicing making supports and was so glad that it had worked.

Name	148
Boys	5
Girls	7
Type	Youth club
Cost	O
Age	7-10

Description

This session was booked by Edinburgh council for one of their younger youth groups.

This was an afterschool youth club which took place in a community centre just off from the school. The group was quite young and seemed quite sensitive with lots of crying and complaining.

The youth workers were really interested in what I was doing which seemed to make the young people more interested as initially they didn't treat me being there as anything unusual and two of the girls said they wanted to colour with crayons instead.

Once we got settled down, I demonstrated how the 3D printer works and the kids were oohing and aaaahing at it. There were lots of questions about how the file was made- it seemed quite difficult to explain what a computer file is to children who weren't familiar with the concept at all. I was using an Ultimaker which has a robot sticker on the side and the children seemed to think that because I was also printing a robot that all they needed to do was do a drawing and stick it on the side of the printer.

One boy was finding it very frustrating, so I spent some time with him showing him the pressure that was necessary to get the plastic to stick. I told him that he just needed to practice but he did keep getting frustrated. Eventually one of the youth workers sat with him and helped him so that I could help other children. At the end of the session the boy who had been struggling had made a model of captain America and seemed really pleased with it before exclaiming, "Practice does make perfect!".

As I was leaving the session a group of the children swarmed round me and said that it was the best day ever doing 3D printing and then they hugged me.

Appendix 4- diary entry form

Name	
Boys	
Girls	
Type	
Cost	
Age	
Description	

Appendix 5- Criteria analysis sheet

Category	A (no. + occ.)	B (no. + occ.)	C (no. + occ.)	D (no. + occ.)
Problem solving				
Social Learning				
Fulfilling and enjoyable activity for children				
Interdisciplinarity of technologies				
Proud of achievement				

Opportunity to communicate with peers about themselves				
Engages a child's focus				
Experience of agency				
Experience of personal capacity				
Project planning				

Satisfaction with outcome				
Opportunity for teamwork				
Interest in production of weapons using 3D printing technology				
Freer communication when making				

Experience of amazement				
Provision of guide increases engagement				

Appendix 6- Tally-checklist sheet

Criteria analysis sheet Date:

Workshop type:

Number of participants:

Category	Occurrence (Yes/No)	Tally of occurrences
Problem solving		
Social learning		
Expression of pride in achievement		
Opportunity to talk to peers about themselves		
Experience of agency		
Satisfaction with outcome		

Appendix 7- Sample lesson plan

Introduction to 3D printing

To successfully implement 3D printing-based learning in a classroom environment it is recommended that 3D printing pens be used alongside the 3D printer and laptops with CAD software. The first four weeks should be spent allowing students and teachers to explore the tools, making whatever they wish. The next four weeks should then be spent ideating, now equipped with knowledge of the limitations of the technology. The final four weeks should be spent using CAD to design a model of the student's choosing. Test prints can be made by scaling the model down to significantly reduce print time.

Equipment required




Week 1-4
Week1:
Demonstration of 3D printer, 3D printing pen, CAD software
Week 2:
Free exploration of any tool.
Week 3:
Free exploration of any tool.
Week 4:
Free exploration of any tool.

Week 5-8
Week5:
Choose something that you want to make with 3D printer. Make plan.
Week 6:
Make 3D printing pen prototype of your model.
Week 7:
Test model and make changes.
Week 8:
Finalise design.

Week 9-12
Week9:
Play with tools in CAD software. Make something 3D. Scale to print in 8 minutes.
Week 10:
Make your design. Scale model so that it prints in 15 mins.
Week 11:
Make final changes to CAD model.
Week 12:
Paint or sand final model.