Exploring service development to scaffold cross-disciplinary critical maker-learning in a Higher Education Academic Library makerspace: A Case Study through the lens of Cultural-Historical Activity Theory.

Robert Curry

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Abstract

This thesis is a US-based case study that analyses the evolution of a university academic library makerspace service supporting experiential maker-learning. Tensions and contradictions are analysed around cross-disciplinary needs, and the developing pragmatics of practice to support inclusive, sustainable maker-learning. The research goal was to address the twin concerns of understanding the nature of the learning occurring and to critically appraise the particular learning affordances the library service offers in this context. Data was obtained from students and academics across disciplines and professional staff in the research contexts of maker-learning occurring in lessons, training, and free activity in the makerspace. Critical understanding was achieved through an engagement with key educational concepts relevant to maker-learning (e.g., ZPD: Zone of Proximal Development, Vygotsky, 1978) in a Cultural-Historical Activity Theory (CHAT, Engeström,1987) framework. The key findings include a new understanding of how maker-learning occurs through social interaction, scaffolded support from academics and professional staff, individual cultural interests *and* embodied curiosity (Radman, 2013) in the material affordances of new and older technologies. For academic library services interested in creating a more inclusive, sustainable, and genuinely cross-faculty makerspace service, the importance of developing a shared ‘common knowledge’ (Edwards, 2017) between academics, professional staff and students is observed. The potential value of *critical* maker-learning for all disciplines, is argued for as a key educational tool for this and other academic library makerspaces. Lastly, to support this argument, I propose and explain my original cross-disciplinary maker-learning concept of ‘Critical Material Awareness’ as a theoretical model for maker-learning design in HE, developed from Matt Ratto’s (2014) concept of ‘Critical Making’.

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Chapter 1 Introduction

1.1 Purpose of study

Makerspaces are based on a simple concept, being a community-based Do-It-Yourself (DIY) space where people come together with an interest in making, learning, exploring and sharing using high tech (e.g., digital fabrication/3D printing, electronics, robotics and virtual reality) or low-tech tools (sewing, woodworking etc.). Makerspaces can be based in communities, schools, museums and universities. Awareness of the potential value of university libraries as inclusive, ‘third spaces’ (open community spaces distinct from work or domestic spheres, Oldenberg, 1989) for maker activities is recognised by key figures associated with current maker culture. For example, David Gauntlett emphasises the individually expressive and socially connective value of making as a path of discovery, learning and growth, stating that ‘Makerspaces invite you to tinker and make whatever you fancy with 3D printers, electronics, wood. Forward-looking libraries open their doors to people who like to create together’ (Gauntlett, 2018, p. 232). In the United Kingdom (UK), makerspaces are an emerging phenomenon with some UK universities such as Strathclyde and University College London (UCL) having adopted them as part of STEM (Science, Technology, Engineering and Mathematics) learning. A few more innovative academic library services (e.g., Edinburgh University) have started cross-disciplinary (including humanities and arts) makerspace services, but makerspaces are still relatively infrequent in UK HE libraries. The strongest examples of academic library makerspace are currently in the US, where the makerspace phenomenon originated.

The focus and aim of this thesis are informed by my professional practice. As a senior professional Academic Librarian (Associate Director for Learning Resources at a UK university), I have responsibility for both Academic Liaison Librarian and Digital Services

(Learning Technology) teams. The Digital Services team as well as supporting critical learning systems such as our Virtual Learning Environment (VLE) Moodle, is also involved in technological experimentation and projects with academics and students using technologies often found in makerspaces including virtual reality, photogrammetry and 3D printing and scanning. Through these professional responsibilities, I have an interest in new educational phenomena that may be developed related to enhancing our educational services. I initially developed an interest in makerspaces as a potential part of an Academic Library service having seen examples appearing worldwide, particularly in America (e.g., Wang *et al.*, 2016). I also became interested in whether a library service makerspace could more easily be designed to be more inclusive than a faculty-based space (e.g., as part of Engineering). Many makerspace communities have difficulty attracting particular demographic groups, 'notably women' (Dellot, 2015, p.7).

Before undertaking the current research, in a professional capacity, I carried out a group interview with colleagues from three American academic libraries hosting makerspaces (Curry, 2017). I found that participants in this study described spaces where students took part in self-directed academic, personal, entrepreneurial and creative activities, as well as more structured taught workshops and lessons. Data showed a mixture of subjects covered in activities including STEM, humanities, art, and history-related activities (which appeared to encourage more female participation). This study led me to look in greater detail at how academics and professional staff might work together to support the learning gains of students using an academic library makerspace and to plan and get approval for an in-depth academic case study on an exemplar Higher Education (HE) makerspace for my Doctorate in Education thesis. My research for this thesis is on a US university library makerspace which has a well-established makerspace service scaffolded by a full programme of workshops and course-related teaching. My bounded case study is designed as an exemplar from an emerging academic library phenomenon to yield salient and detailed information with relevance to other HE libraries, particularly those less aware of the evolving maker culture and related educational possibilities.

Although the Covid-19 pandemic (which hit after I had carried out my empirical on-site research) has accelerated many HE institution's operations and planning around blended learning, I have not found the need to fundamentally re-evaluate the value of my research. Although digital off-site learning may become more prevalent in HE, it is my contention that the value of face-to-face contact with academics, support staff and other students will remain integral as students look for more meaningful experiential learning opportunities to balance against more basic learning that has been 'flipped'. Embodied, critical maker-learning with new technology and material interactions could therefore become a part of new experiential on-site learning opportunities. A corollary purpose of this study is thus to use insights from the case study around critical and embodied learning to build a new higher-education concept of Critical Material Awareness as an original contribution to knowledge. As academic library study spaces, technologies and tools evolve with new technologies and services, potentially the concept of 'learning resources' expands with it. So too could cultural definitions of Library and Information Science and the very nature of library and information work, potentially globally. As anthropologist Catherine Hasse observes: 'the multistable character of material artefacts can affect professional agency and expertise in unforeseeable ways and even change professional identities.' (2015, p. 281).

1.2 Introducing makerspace culture and maker-learning

As the core idea is simple, everything from a small maker activity in a class (e.g., using Raspberry Pi microcomputing) to expensive, high-tech spaces in university engineering departments with specialist hardware (e.g., high-end 3D printers, scanners, Computer-Numerical-Control (CNC) machinery and power tools) can be called a makerspace. Makerspaces are a relatively recent phenomenon emerging from related technology-based creative community spaces such as Fab Labs (small scale digital fabrication workshops) and Hackerspaces. 'Hacker' is a term that is often used pejoratively by the media to describe people who illegally break into computers. In maker-culture, however, 'hacker' is a positive term for creative programmers tweaking code for new purposes (Davies, 2017). Makerspaces were popularised first in the US by Dale Dougherty, who started Make magazine in 2005. The 'maker movement' promoted and popularised initially by Dougherty's company Maker Media, has a manifesto that defines maker culture within an essentially humanist frame: 'Making is fundamental to what it means to be human. We must make, create and express ourselves to feel whole' (Hatch, 2014, p.1). The movement also incorporates what it calls Maker Faires showcasing innovative products. There is a small but growing body of literature researching makerspaces which I will go on to explore. A key early piece of research in the literature, Sheridan *et al.* (2014), observes the following key themes in maker-learning: multidisciplinarity, the blending of formal learning and communities of shared practice, and a 'focus on learning as production rather than mastery of a composite set of skills' (Sheridan *et al.*, 2014, p.526). This remains the ethos of the movement. I found in this thesis tensions between aspects of the maker movement and its emergence in HE as a learning environment. I shall explain how there are possibilities for a more critical take on 'maker-learning' than those currently on offer in the Academy, addressing current HE issues including sustainability, inclusivity and increasing opportunities for new learning affordances from cross-disciplinary creative space.

Therefore, as an evolving educational concept defining ‘maker-learning’ is problematic as it can be seen to be contested from different cultural and academic perspectives that I will go on to explore in depth in this thesis. For example from an engineering perspective ‘maker-learning’ can be seen as an entry level creative activity on the way to being a professional engineer. However, it is my contention born-out by the research I show in this thesis ‘maker-learning’, not thought of as a simple tool to introduce engineering concepts, has the capacity to become a complex multi-faceted *system* of critical learning within HE whereby artistic, humanist and scientific interests can be brought together. Taken as an emancipatory and creative learning opportunity from different disciplinary perspectives as shown in this case study, *critical* maker-learning becomes an opportunity to radically re-think all disciplines’ relationship to material culture and critical material literacy such that the neo-liberal drive for skills for careers does not have to be in contradiction with the more emancipatory push for a critical education.

1.3 Introduction to the case study site and research approach

The makerspace I primarily focus on in this research is the second (Campus 2) one built at the research site, a much larger one than the one that was initially created (Campus 1). The new, expanded maker service thus allowed for many and varied training and maker activities to occur, rather than just being essentially a 3D printing service. There now follows an introductory descriptive vignette of the Campus 2 makerspace so readers can orientate themselves (photos of the space and some of the objects mentioned below can be found in

Appendix 9) before I address the wider context in the literature review, and a brief introduction to my research approach which will be looked at in more detail in the theoretical framework and methodology chapters.

The case study university has a number of makerspaces including two large engineering spaces and an ‘entrepreneurship garage’. The library service makerspaces are different to the others as they welcome students across all disciplines. When I first saw the Campus 2 library makerspace, my impression was of a secure, rectangular space located near the main library’s issue and enquiry point, behind clear glass and approximately 55 square meters in size. Next to the entrance on the left was a video screen advertising opening hours, activities and training. On the right, there was a display of various items that had been made in the makerspace with brief descriptions. All had a clear educational purpose, for example a molecular puzzle (Appendix 9, Image 10), a model of the solar system (Image 8), a creative reimagining of a stone tablet with cuneiform writing on it (Image 11), and a ‘story cube’ which used the Microsoft HoloLens Headset to create an augmented reality ‘multi-dimensional text’ display from a 3D printed Soma puzzle cube. Other items included 3D scanned eighteenth and nineteenth-century artefacts for a digital history project between the university and a local museum, and a prototype ‘CubeSet’ (a type of miniature satellite that allows for affordable scientific research in space) made in the makerspace by a student who is now a NASA intern. This showed a deliberate move to showcase cross-disciplinary items of pedagogical value, as well as occasional ‘fun’ projects.

On entering the makerspace, my first impression was a very well organised, clean and tidy space. Behind an enquiry desk straight ahead could be seen various books and magazines relevant to the maker movement (Image 9, e.g., a 3D Printing Handbook, and a guide from Make magazine on getting started with Arduino, guides on electronics, a 'sew electric' manual, and an introduction to TinkerCad). The makerspace stretched out on my right in various sections. A small entrance desk with a number counter (made in the makerspace) was followed by three large wooden desks with fifteen seats in total. On the right was a series of five 3D printers (Image 7) and a 3D scanner with lockers that could be used underneath. On the left were a laser cutter (Image 3) and various pieces of equipment that could be brought out for use, including sewing machines and Adafruit 'circuit playgrounds' for quickly prototyping projects (built-in components included a motion sensor, light sensor, sound sensor and temperature sensor). A wide variety of equipment also available to borrow included SparkFun Arduino inventor kits, Internet of Things starter kits, Raspberry Pi mini-computers, a Celestron Handheld Microscope and a Moog Werkstatt-01 Analog Synthesiser. Various tools (Image 6) such as wire cutters and hammers were available and were neatly organised, as was protective equipment including gloves and masks.

The ethos for the use of the case study makerspace that I found in my research was very much one of taking pride in looking after this shared space and leaving it as you found it. Hanging up next to the tools was a dustpan and brush. Unlike some other makerspaces I have been in, it was spotless, with no discernable smells, with a feeling of space and light helped an outside window and the fact that the whole area was enclosed by clear glass. Additional power could be pulled down from socket units attached high up in the space, and a large display screen connected to a PC could be pulled down for training purposes. Although this cleaner, more academic feel could be seen as contradicting the tinkering DIY ethos found in public makerspaces, the need to provide a level of equality between different kinds of users encouraged a 'tidy up and put away' culture. Thus, tensions between different disciplinary uses of the space were mitigated to an extent. However, as I shall go on to show the following chapters, the choice of technologies purchased and supported could in itself lead to tensions around perceived bias.

Services I found currently in operation at the case study site included a diverse range of 58 current makerspace workshops (including 3D Design, Digital Embroidery and Critical Making for Sustainability) and technologies for borrowing including 3D printers and scanners, Arduino inventor kits, Internet of Things starter pack and Raspberry Pi (full details can be found in Appendix 6). Data also showed an average attendance for course-based makerspace sessions and workshops of 15 people – the maximum capacity of the larger of the two makerspaces that is used for teaching and training. In the 2019 academic year, there were 41 course-based sessions, 146 workshops and 20 other activities. As I will show in the literature review- not all academic library makerspaces are able to hold the same cross-disciplinary variety of teaching and training or to attract consistently high student numbers to the same extent.

As I shall explain in the theoretical framework and methodology chapters I have chosen an interpretive case study approach to look, in a critical manner, at the evolution of this maker service and the kind of cross-disciplinary learning affordances that have been created. As Yin observes, interpretive case studies require multiple forms of evidence (e.g., interview, direct observation, documents, physical artefacts) and different participant perspectives to observe human events and behaviour. This approach fits well with Yrjö Engeström's (1987) third generation of Cultural-Historical Activity Theory (CHAT), which I will outline in the theoretical framework with its multiple perspectives and mediating artefacts within an activity system: 'the use of multiple sources of evidence in case studies allows an investigator to address a broader range of historical and behavioural issues' (Yin, p.115). For my research, the ‘activity’ systems I look at are how librarians, academics and communities of interest around different technologies try to meet students’ emerging makerspace-related information and digital literacy needs (the goal being to provide useful support services, with the outcome of increasing makerspace learning affordances and educational development). The triangulation of perspectives comes from academics, professional library support staff and students. As Yin advises, I have also included a wide palette of perspectives including participants who have critical views of the research object and are more cynical about makerspaces’ educational possibilities. Thus, the triangulation is not just aimed at seeing where facts and observations can be corroborated, but where different perspectives allow for a more multi-faceted view of the research object: ‘to pick triangulation sources that have different biases, different strengths, so they can “complement” each other’ (Miles and Huberman, 1994, p.267).

Thus, with much to learn from this case site and with only a small amount of detailed academic library makerspace research to date, it was worthwhile taking an in-depth case study approach. This was achieved through semi-structured interviews, observation of makerspace activities, and analysis of documents and quantitative data provided by the research site as I shall show. This research should prove to be of interest not just for my practice but throughout UK higher education (HE) libraries (and potentially HE libraries in other countries relatively new to this phenomenon), as we navigate through the competing educational value of new service opportunities such as makerspace.

1.4 Research Questions

Below is the initial core question, and sub-questions for this thesis.

Core Question

How can an academic library makerspace develop as an inclusive cross-disciplinary learning space and service within a Higher Education Institution?

Sub questions

- How did the case-study library makerspace service evolve beyond initial challenges and tensions to aim to support expansive, inclusive embodied cross-disciplinary learning?
- How are apparent contradictions between the learning objectives of different user groups addressed in the library makerspace service?
- Is the lack of gender and social diversity in STEM (Science, Technology, Engineering and Mathematics) challenged by this library makerspace service?
- What are the main tensions and contradictions that need to be addressed to further scaffold 'critical' maker-learning in the library makerspace service?

1.5 Overview of the thesis

In Chapter 2 I go on to show the necessity in this thesis of marshalling concepts from four domains of learning and information theory. I explain how the concepts I introduce have emerged from sociocultural perspectives, experiential theory on learning by doing, embodied learning from cognitive and neuroscientific knowledge, and my central professional viewpoint defined in library and information science terms. These concepts are brought together in order to achieve a holistic view of maker-learning in this context as an exploratory, embodied material-based learning, also reliant on technology-based communities of interest scaffolded by professional support. Having established the conceptual framework for this study in Chapter 2, Chapter 3 looks at critical views on makerspaces, the maker movement and maker-learning. It problematises specific aspects of maker-learning, particularly makerspaces' potential to provide technological 'mastery' in a meaningful and inclusive way. I draw out the developing prospect for maker-learning within HE as sites for critical and authentic learning. I also identify significant gaps in knowledge within the existing literature which I explore in this thesis.

In the theoretical framework (Chapter 4) I show how I am using the explanatory power of Cultural-Historical Activity Theory (Engeström, 1987) as an overarching framework to explain the emerging organisational tensions met and addressed during this academic library's project to progress makerspace services. The limitations of CHAT are also examined, including how individual agency can get lost in the analysis of system-based change. I explain how Anne Edwards' relational concepts (2017) mitigate against this limitation and have enabled me to include analysis of the cross-practice work essential for organisational change. In Chapter 5 the reason for the multiple-methods interpretive methodology is explained as the appropriate approach for this newly emerging phenomenon, as an exploratory case study from my paradigm of Socio-Critical Realism. Ethical considerations are covered, including *primum non nocere* (do no harm) and looking to benefit participants through an inclusive approach to data collection. Methods for data collection and the triangulation of a purposeful selection of participants and research instruments used are described in full to achieve case study validity. Data collection activities are then summarised. The analytical process is explained, including the tools I engage with for observing information retrieval behaviour (Sense Making, Dervin, 2003) and for broader CHAT themes (Template Analysis, King 2016).

Chapter 6 examines the historical emergence of the research object - in this case, the higher-education academic library makerspace, through the use of empirical data from documents and the analysis of semi-structured interviews. The particular way the academic library service has had to adjust to scaffold learning affordances in this new learning space is considered. The emergence of the educational perspectives of Critical Making (from the library and information community, Ratto, 2014) and Digital Humanities (through the lens of the English department at the case study university) are analysed in terms of how these particular perspectives on maker-learning may open up more inclusive cross-disciplinary opportunities for the makerspace service. Chapter 7 moves on to cover an in-depth look at maker-learning across disciplines through an ontological picture balancing practical, embodied and critical modes of Constructivist learning found in the case study. Key challenges for maker-learning in HE are drawn out, including the need to avoid a STEM only learning paradigm through concepts from Critical Making and Digital Humanities.

The key interrelated themes of inclusivity and diversity are addressed in chapter 8. This chapter focuses on the level of inclusivity this makerspace service has achieved through looking at maker-learning from different disciplinary perspectives. The extent of successful scaffolding for genuinely diverse maker-learning is examined. I analyse the evolving role of academic librarians in the makerspace context as interpreters of different academic and student needs. In Chapter 9 I then go on to introduce my model for building HE-based cross-disciplinary maker-learning opportunities that aim to empower students through the combination of my concept of Critical Material Awareness and practical maker-learning aims. I then apply the key learning from this thesis to a new vision for HE-based maker-learning, whereby the neo-liberal focus on practical career aims within HE is no longer in contradiction with the critical/humanistic potential of academic library-based makerspace services. In my conclusion (Chapter 10) I discuss my key contributions to knowledge, including insights into the evolving role of academic librarians as central to scaffolding cross-disciplinary learning through relational expertise, and the cross-disciplinary critical maker-learning pedagogy I put forward through my model. I also further explain my observations on the nature of maker-learning in terms of its sociocultural, embodied and haptic elements.

Appendices

The appendices include examples of interview schedules, data analysis, direct observation field notes and documents shared from the research site on the makerspace service. Details of the analytical process for all data collected are included, as well a table of ethical considerations and actions.

1.6 Chapter 1 Summary

I have described my professional perspective as an academic librarian and interest in makerspaces, the purpose and case study and a vignette of the case study site and summarised the content of this thesis. The significance of this case study is shown as having two key elements. Firstly, this thesis is an in depth look at how an academic library makerspace needs to evolve through tensions and contradictions with existing services in order to effectively accommodate maker-learning services. Secondly, the nature of maker-learning is explored in depth in this context whereby additional learning affordances are scaffolded by professional support, thus adding to the richness of the exploratory, embodied experiential learning observed. I now go on to look at the key learning theory I found to be relevant to my case study.

Chapter 2 Literature Review Part 1 Key Learning Theory

2.1 Introduction

I now go on to look at critical areas of learning theory that are salient to my study starting with the sociocultural theories most often associated with maker-learning, before a detailed exploration (literature review- part 2) of the evolution of maker-learning culture and its emergence in HE and specifically HE libraries. This thesis aims to bridge a theory gap between ‘sociocultural’ and ‘experiential’ perspectives on learning, emerging educational thought around ‘embodied’ learning, and critical theory from Library and Information Science (henceforth LIS). In order to give an authentic and honest appraisal of the complexity I found in maker-learning in this context broad theoretical scaffolding across four conceptual fields was necessary. It was clearly challenging to move into a new cross theoretical space, and in this chapter, I offer an introductory picture of the learning theory engaged with in this thesis which I go on to connect with research into maker-learning to date in part 2 of the literature review (Chapter 3) and with my Cultural-Historical Activity Theory research framework in Chapter 4. The complexity of my theorising is then scaffolded gradually into the thesis through my empirical research and observations, before coming together in my theory building and insights at the end of the thesis. I accepted this complex challenge as I felt it was essential in order to fully contribute to maker-learning knowledge to open up horizons of understanding across domains of educational theory, to more fully understand and explain the new cross-disciplinary learning emerging in a makerspace in this higher education context.

Although the experiential learning found in makerspaces is inherent in learning models for more ‘vocational’ subjects, there are further possibilities around ‘critical’ maker-learning that I will show can be incorporated into more ‘academic’ subjects such as English (through educational phenomena such as maker-related Digital Humanities projects, which explore technology in relation to human experience, history and culture). This thesis takes a sociocultural view of experiential learning that is opposed to a deterministic ‘brain’- based understanding of mind. As Donald (2001, p. 150) argues,

> Culture distributes cognitive activity across many brains and dominates the mind of members. Despite this, cognitive science studies the mind as if it were confined entirely within a single brain.

This perspective is in keeping with my (critical) scientific realist view, and *contra* more reductionist models that much modern ‘hard science’ is itself questioning. As Adam Rutherford remarks, ‘It might seem odd that a geneticist should want to play down the significance of genes, but the fact is we are social beings who have offloaded so much of our bodily hardware into our cultural software’ (Rutherford, 2020, p.174). Makerspaces, as I shall show, can be seen as kind of community based social learning ‘software’ employing technological hardware.

The sequence of this Chapter is to look at relevant parts of the conceptual fields mentioned in the following order: Sociocultural Theory (including Activity Theory), Experiential Learning, Embodied Learning, and Library and Information Science.

2.2 Sociocultural Theory

2.2.1 Activity Theory

Makerspaces are inherently contexts for action and material-based activity with individual and group objectives. I have found ‘Activity Theory’, first developed in the work of the Russian psychologist Lev Vygotsky (1896-1934), to be an established cultural and scientific theory relevant to the needs of my case study. This approach theorises how social development (not just education-based) involves a subject (individual, group) using mediational means (tools) to achieve an object (outcome, goal). Vygotsky’s focus is on how human agency is enacted through the mediation of tools, signs and artefacts, as in my case study when an innovative and critical makerspace-based learning project comes to fruition creating new knowledge and possibilities for those involved around technology-based learning affordances. As collective human agency is a core part of Vygotsky’s thought, his dialectical model is removed from ‘the domain of crude social determinism’ (Daniels, 2015, p.35) and is compatible with reason-based critical and emancipatory theorising. Tools (or mediating artefacts) and signs in Activity Theory are seen as aspects of the same phenomenon influencing both the agent and structure; tools being technical and signs being psychological (e.g., writing, language, gesture, diagrams, concepts, machines- all of which are present in maker-learning) (Vygotsky, 1978). Alexei Leont’ev (1903-1970) further developed the Vygotskian notion of activity through the idea of three-level strata to the activity (activity, action, operation). Leont’ev looked at the many ways an activity can be enacted**,** including how an action that initially required thoughtful attention to a goal can become routinised to the extent that it is incorporated within a more encompassing action. For example, mental arithmetic using multiplication rather than sums using a pencil and paper (Wells & Edwards, 2013, p.9), or from my case study foundational learning on maker technology being employed in increasingly complex project aims and outcomes.

As mentioned in the introduction, I utilise a later development of Activity Theory, Cultural Historical Activity Theory (CHAT, developed by Yrjö Engeström 1987). I will go on to explain CHAT in more detail in the theoretical framework chapter, along with Anne Edwards (2017) Relational Concepts which I use to critique and expand on aspects of CHAT theory that can be seen to reduce research analysis to mediating artefacts and organisational factors, rather than human agency. Edwards' concepts enabled me to look in-depth at how academic librarians worked with scholars from different disciplines and as well as with other professional staff on complex problems to build 'common knowledge' (Edwards, 2017) of the services that became valuable in support of maker-learning.

2.2.2 Communities of Practice

'Communities of Practice' (Lave & Wenger, 1991) is a sociocultural concept often associated with makerspaces and seen as at the heart of maker-learning. Communities of Practice (henceforth CoP) are groups of people who share a craft, profession or area of expertise and practice. Group members learn from each other and develop personally and professionally. In an educational context, the development of CoP can be seen to facilitate and scaffold learning opportunities, rather than designing educational models that are highly prescriptive: '*Learning cannot be designed* [emphasis in the original]*:* it can only be designed *for* - that is, facilitated or frustrated' (Wenger, 1998, p.229). CoP is frequently employed as a lens when looking at makerspaces (e.g., Sheridan *et al.*, 2014; McGrath & Guglielmo, 2015). A shared domain of interest is an integral part of CoP theory, so it resonates with maker culture: '*making* broadly construed becomes the shared domain' (Sheridan *et al.*, 2014, p.509). CoP was theorised initially in 'Situated Learning: Legitimate Peripheral Participation' (Lave & Wenger, 1991) which emphasises the situational context and culture in which learning occurs, and the possible importance of authenticity to the cultural context for helping knowledge creation. Students may choose to join in the activities in a makerspace through observing others working in the space first. Despite the salience of CoP theory, I have decided to adopt the broader explanatory framework of Cultural-Historical Activity Theory (CHAT, Engeström, 1987) to look at organisational development through dialectical cultural tensions to meet new maker-learning needs. Although communities can and do form around a makerspace, they are more experimental and demonstrate a more collaborative DIY ethos than can be found in the shared expertise often found in CoP. Also, one makerspace may have multiple, informal short and longer-lived communities forming around intersections of particular technologies, disciplinary perspectives and student peer-group interests.

2.2.3 Self-Efficacy

In my research, I also identified Self-Efficacy through social learning (Bandura, 1997) as a relevant concept. Makerspace participants experience an immediate primary connection to the quality of their designs and creations as they are involved in a process which can be seen as encouraging a kind of digital craftsmanship. Creative outcomes are achieved through the encouragement of a particular sort of self-efficacy, in terms of patience and thoughtfulness within an individual's psychology, required for the process. This patient, reflective community-based peer learning in the making process can also be seen as encouraging a kind of positive and progressive social communication that fits with collaborative humanistic values. As Sennett (2008, p. 289) argues, patiently crafting material things is transferable to relational skills as: 'people need to practice their relations with one another, learn the skills of anticipation and revision to improve these relations'. Makerspaces are an opportunity for this patient, relational kind of learning and self and group efficacy building.

2.2.4 Zone of Proximal Development (ZPD)

The Zone of Proximal Development (ZPD) proposed by Lev Vygotsky (1978) encompasses the range of abilities an individual can employ with assistance, but not yet on their own. This concept, concerned with individuals learning from more capable peers as in a Community of Practice (as above), was expanded by Engeström (1987) to a collective cross-boundary level. Thus, in an educational context, 'teaching and learning are moving within the zone only when they are developing historically new forms of activity' (Engeström, 1987, p.147). In my case study the ZPD operates in a professional context between academic library staff and academics from different disciplines. All involved in this process learned from each other's specific expertise ahead of their own to create new maker-learning possibilities in a social-constructivist manner. However, this co-construction of maker-learning common knowledge is not without emerging tensions which I go on to explore. As well as offering critiques and understanding from the case study site, this thesis goes on (in chapters 8, 9 and 10) to develop theoretical and practical insights to develop a new form of critical maker-learning in HE.

2.3 Experiential Learning

2.3.1 Authentic Learning

'Authentic Learning' can be considered as that which focuses on real-world problems through experiential, hands-on creative individual and group projects, and problem-based activities often developed through participation in CoP. Lombardi (2007, p. 3) reminds us that 'Authentic learning intentionally brings into play multiple disciplines, multiple perspectives, ways of working, habits of mind, and community'. Authentic learning aims to develop expertise across all four domains of learning: Cognitive, Affective, Psychomotor and Conative; particularly Conative, constituting the capacity to 'act, decide and commit'

(Lombardi, 2007, p.8). Makerspaces can be broadly linked to this type of ‘experiential learning’ since much makerspace activity involves learning-by-doing activities that engage with real-world problems, needs, or issues, and enable us to reflect on the activity. The philosopher John Dewey’s educational thought is relevant here. It is cited by current researchers of maker-learning (e.g., Sheridan *et al.*, 2014) as I shall show in part 2 of the literature review because it provides insight into how a makerspace can provide a potentially worthwhile educational environment. Dewey emphasises the importance of practical, experiential student-oriented learning, with students learning through observation, problem-solving and enquiry, potentially uniting the division between knowledge and action:

> The science and philosophy of education can and should work together in overcoming the split between …theory and practice, which now affects both education and society so seriously and harmfully. (Dewey, 1964, p.19)

A makerspace can be seen as a modern cross-disciplinary space away from fixed ideas of subject knowledge and disciplinary boundaries that concerned Dewey in his lifetime: ‘A pupil can say he ‘had’ a subject, because the subject has been treated as if it were complete in itself, beginning and terminating within limits fixed in advance’ (Dewey,1964, p.425). Dewey’s emphasis on the possibility of a sufficient balance between learning through both playfulness and seriousness also seems relevant to makerspaces: ‘To be playful and serious at the same time is possible…[and] defines the ideal mental condition’, by showing an ‘absence of dogmatism and prejudice’ and the ‘presence of intellectual curiosity and flexibility’ (Dewey, 1909, p.219). As later scholars such as Aria Razfar point out, Dewey and Vygotsky share a commonality (though never having met, and the influence is one way with Vygotsky’s writing not appearing in English until after Dewey’s death). A fundamental overlap in their thought involves having an interest in experiential learning that involves ‘an active learner engaged in creative construction of knowledge through collaboration' (Razfar, 2013 p.129). Both can also be seen to value pedagogic design that emphasises the importance of 'activities that reposition learners to assume greater responsibility for learning and authentic problem solving' (Ibid.). However, the 'authenticity' in makerspace learning can be challenged as I shall go on to show in my ontological analysis of maker-learning (Chapter 7) as makerspaces can be controlled and simulated digitally reliant environments where outcomes may often be experimental or educational, rather than necessarily having real-world impact.

2.3.2 Constructionism

The computer scientist Seymour Papert (1928-2016) developed the theory of Constructionism (Papert, 1991) as a pedagogical approach principally for younger students that builds on Constructivism's (Piaget, 1937) emphasis on learning as mental construction undertaken by individuals reflecting on personal experiences. Papert focused particularly on the mediating learning affordance of the creation and manipulation of material objects, often though the digital interface of computers (and is thus a key thinker in the path to the kind of often digitally enabled activities found in makerspaces). Constructionism claims that knowledge can be constructed through the particular developmental efficacy of building things that are tangible and shareable public objects:

> You don't need to be taught in order to learn. This is not to say the teacher is not an important part of the learning process… But recognising the importance of the teacher is very different from reducing learning to the passive side of being taught. (Papert, 1990)

Although more often associated with education for children Papert's Constructionism, with its Deweyan emphasis on playfulness as a receptive state of mind for learning, is relevant for all age groups participating in maker-learning as enjoyment in the projects and activities in maker-learning was a key factor in the learning I found in this case study and in the literature to date. I shall go on to show this in the literature review part 2, and further insights from this case study as we observe how maker-learning makes its way into an HE context.

2.3.3 Critical Making

Matt Ratto's 'Critical Making' approach to learning, developed at the University of Toronto's Faculty of Information Critical Making lab, can be described as a kind of moral and values-based Constructionism (as above), building as it does an experiential learning process that involves critical reflection on the values in the design and materials used in the shared act of making. This approach links lived experiences with technologies to social critiques which include incorporating the critical history of technology, activism and anti-neo-liberal politics. The aim of critical thinking through embodied, material-engaged learning was initially more important than creating a tangible or usable object (Ratto, 2014): 'Critical making frames a need to incorporate technical work alongside critical social analysis and makes a claim that doing so can both extend current scholarly critiques and direct them into society' (Ratto, 2012, p.2). A recent example from the Critical Making Lab shows how its open design practice has extended beyond the purely critical. Kleiner (2019) reports on how Ratto worked with doctors at the Toronto General Hospital to create a lab with the remit to translate 3D imaging, modelling and micromanufacturing techniques into clinical and educational practice. This work resulted in outcomes which included accurate 3D-printed hearts that allowed doctors to better examine heart defects before operating to repair them, as well as providing effective pedagogical models.

2.4 Embodied Learning

In this thesis, I identify and marshal concepts emerging from the field of 'Embodied Learning' scholarship to inform my study through the realisation that the embodied nature of maker-learning is integral to the kind of social-constructivism shown through the theories thus far described. Embodied learning has to date been small area of research in the social sciences not in full dialogue with emerging cognitive science perspectives. 'Embodied Learning' is based on a view of cognition from neuroscientific and behavioural research which recognises that 'thinking' is never purely in the brain, but instead grounded in sensory and motor experiences from the whole body. Recent learning sciences research suggests learning is best achieved through a balance between culturally embedded rational/logical/inferential individual thought and communities of collective interest (defined in terms of *being for others* and *building identity* for individuals as part of a wider group), *and* the experiential/intuitive *becoming* of individual human embodied experience. As Claxton (2015, p. 239) has argued, 'in practice, these non-intellectual, more embodied ways of learning and knowing blend together with thinking of a more rational and explicit kind.'

Although the social and experiential nature of makerspace learning is apparent in the 'learning by doing' model, the 'embodied' aspect of makerspace learning has not been addressed to any great extent yet in the literature. The idea that the human 'mind' as a fully-embodied phenomenon that is dependent on physical action for development has been developed in the learning sciences in recent decades but was initially suggested by phenomenological perspectives. Notably, Martin Heidegger proposed the idea of 'handiness' (1962) as the ontological categorical definition of beings as they are 'in themselves', seeing objects and using them for tasks. In Maurice Merleau-Ponty's 'Phenomenology of Perception' (1962), material tools are understood as sometimes, with regular use, becoming extensions of our mind. These ideas have more recently been applied within research in the learning sciences to the study of tools as cognitive extensions of our 'body schema': 'The tools and resources we use literally become incorporated into the body's working definition of itself' (Claxton, p.292, 2016). The hand, in particular, has been identified as a crucial human tool we use to think with: 'Manual perception, just like visual and auditory perception, helps discriminate the relevant from the accidental, the 'meaningful' from the 'invisible', and the 'doable' from the 'unhandy' (Radman, 2013, p.388). Thus, in a maker-learning context I have found the tools available are often explored physically and haptically (using the sense of touch through tactile and related kinaesthetic sensations) at the same time as intellectually and creatively (see my ontology of maker-learning, Chapter 7).

Although some makerspace activities are often reliant on a digital interface, for example 3D printing from PC based software, much else involves embodied and haptic material manipulation and exploration. Material manipulation is involved in designing and using learning puzzles, sewing electronics into fabrics, traditional arts and crafts activities that can occur in makerspaces as well as more socio-critical maker projects. Even when reliant on a digital interface, maker creations such as 3D prints can be used as objects to touch and manipulate (e.g., a student-created model of the solar system which I observe in the case study (see Appendix 7), and other examples I shall go on to discuss).

2.5 Library and Information Science (LIS) Concepts

To explain how the professional perspective I have as an Academic Librarian evolved through dialogue with academics and IT staff building common knowledge around maker-learning, I now go on to describe the critical Library and Information Science (LIS) concepts relevant to this thesis.

2.5.1 Information Literacy

From a Library and Information Science (LIS) perspective the first key concept employed in this thesis is ‘Information Literacy’. This concept can be defined as the ability to ‘think critically and make balanced judgements about any information we find and use’, thus enabling people to ‘reach and express informed views and to engage with society’ (Chartered Institute of Library and Information Professionals [CILIP], 2018). As an information professional, I find a sociocultural view of ‘information’ as a historically and culturally situated and contextual phenomenon the most sensible way to view it. This view has become more influential in recent LIS history (e.g., ‘information literacy is a situated practice that is shaped through the interactions between people’, Lloyd, 2010, p.182). This thesis explores how critical information literacy support in the case study makerspace is dialogically built through interactions between student needs and library staff support (interpreting students’ disciplinary perspective in a maker-learning context). Thus, information needs are examined as they emerge experientially in the space, as well as through more formal planned teaching.

2.5.2 Critical Information Literacy

My second key LIS concept is ‘Critical Information Literacy’. This concept is defined by Eamon Tewell (2018, p. 1) as a way of thinking that examines the social construction and political dimensions of libraries and information, problematising information’s production and use so that library users may think critically about such forces. From my practice, much of my information literacy pedagogy has been problem-based; for example, critically evaluating climate change information from different perspectives. In my recent praxis, more scientifically reliable resources were contrasted with the alt-right influenced anti-scientific realism based on the (lack of) ‘information’ on climate change found on the US government website under the Trump presidency (with most of the relevant science suppressed).

The critical-pedagogy I am most indebted to for my (critical) information literacy teaching is the emancipatory theories of Brazilian educator Paulo Freire (1921-1997). Freire’s emphasis is on critical pedagogy empowering learners to be able to transform their world through a logical understanding of present systems. Friere reminds us that **‘**Problem-posing education… enables teachers and students to become Subjects of the educational process by overcoming authoritarianism.’ (1970, p.67). As I have explored maker-learning in more depth it has become apparent that the concepts from Activity Theory (notably the ZPD), CHAT, and embodied critical maker-learning fit well with more radical possibilities for maker-learning. Freire’s problem posing emancipatory theorising can become relevant in the embodied awareness of new technologies in community-based maker-learning, and the fundamental cross-disciplinary realisation that no one has to leave university with a sense of just being a passive consumer of material culture. I go on to explore these more radical possibilities for maker-learning as I build theory in the later chapters of this thesis.

2.5.3 Digital Literacy

The third key LIS concept salient to my study is ‘Digital Literacy’: For my thesis, this expanding concept is defined as: ‘Those capabilities that fit someone for living, learning, working, participating and thriving in a digital society’ (Health Education England, 2018, n.p.). These include technical abilities, awareness of digital identity and safety, the use of collaborative online tools, and the ability to understand and make balanced judgements about data. Although makerspaces involve ‘learning affordances’ from embodied/material interaction in shared physical spaces, there is often the need for a digital interface in the creative process, for example using the software ‘Tinkercad’ on a PC before 3D printing. A learning ‘affordance’ in this thesis can be defined as the possibilities for action in educational situations, and in the using and making of artefacts (Jackson, 2020). It was interesting in this case study that the Virtual Reality (VR) technologies were quickly established as a separate service. As I shall show despite the use of digital interfaces for many of the technologies the makerspace learning I observed involved material interactions and material outcomes, so could only be considered partly ‘virtual’. I shall go on to explore the ontological implications of this in Chapter 7.

2.6 Summary of Chapter 2

This chapter has shown the necessity in this thesis of marshalling concepts from four domains of learning and information theory. These domains and relevant learning concepts I have introduced have emerged from sociocultural perspectives, experiential theory on learning by doing, embodied learning that is emerging from cognitive and neuroscientific knowledge, and my central professional viewpoint defined in library and information science terms. Whilst the sociocultural view is essential for understanding the cross-boundary cultural change required in the evolution of this academic library service and the cross-disciplinary social learning integral to maker-learning, experiential and embodied perspectives show how the material interaction and haptic curiosity add powerful elements to a view of critical maker-learning that can challenge more passive consumer-based material culture.

Chapter 3 Literature Review Part 2 Critical Views

3.1 Introduction

I now move on, in part 2 of this literature review, to look at the literature on makerspaces, and specifically how they have emerged as cross-disciplinary experiential learning spaces run by higher education library services. Thus, this chapter takes a cultural-historical and critical view of makerspaces within the context of new academic library services trying to meet the emerging needs of their host university. As well as discussing the potential educational value of these spaces, I examine critical views of the makerspace movement, which raise questions about inclusivity and sustainability. I will consider the tensions/contradictions between how a university library makerspace operates and wider maker-culture. The chapter covers how the makerspace phenomenon may fit in with professional moves to update academic library services, as well as the emergence of maker-culture and how it has been interpreted critically within the Academy. I observe how maker-learning in HE potentially links with progressive educational aims for authentic experiential learning that also employ critical thinking. At the end of this chapter, I identify the additional,more detailed questions and the gaps in research knowledge this literature review has prompted that are looked at in-depth in this case study. As it looks at a recently emerging phenomenon, this literature review is as much about the key things, from my research perspective, missing from the current literature as what I have found that has been useful to review. At the end of this chapter, I will identify the specific gaps in the existing literature that my thesis attempts to fill.

3.2 Challenges for academic libraries

According to the UK's Society of College, National and University Libraries (SCONUL) report on 'Mapping the future of academic libraries' that looks at the next ten years (Pinfield, Cox and Rutter, 2017), academic libraries operate in a fast-changing environment that is consistently challenging their current and future worth. Trends include ongoing increases in the use of e-resource such as ebooks (and a related downward trend in hard copy); meeting the needs of increasingly 'datafied' scholarship and the open access agenda; and the intense political and economic pressures of a currently market-driven environment. The report shows to adapt to the new Higher Education (HE) landscape many UK academic libraries are shifting their strategic emphasis from collections to services such as information and digital literacy support, scholarly communications and co-designing online content. These services are contextual and focused on the particular needs of the specific Higher Education Institution (HEI).

Perhaps the most strident attack on the future worth of academic libraries has come from academic librarian Jeffrey Beall in his article 'Glamorised study halls do not need an army of librarians' (2019) in the Times Higher Education magazine (*THE*). Beall is best known within the Library and Information Science (LIS) community for his investigations of predatory open-access publishers with allegedly poor-quality control. In the article, Beall critiques American library services for still maintaining large staff and bureaucracies, despite the apparently diminishing value of the library and librarianship with the rise of Google and internet access to information. Beall views modern academic libraries as 'little more than glamorised study halls' (p.2), and university librarians as 'left wing zealots' (p.2) with too much time on their hands for virtue signaling. The counter argument to this piece can be found in many online responses. For example, Beth Montague-Hellen (2019) argues that our

Google age of easily accessible but often unreliable information requires more information and digital literacy support rather than less. This counter argument does not, however, negate some of Beall's points about the purpose of modern academic library space which, while often protecting valuable quiet study space, do sometimes also seem to promote socialising rather than social learning in other study spaces.

In their recent research report, LIS scholars Pinfield, Cox and Rutter (2017) identify trends in academia that underpin ideas for new academic library services, including 'connected learning' whereby 'learning is increasingly seen as social and more intensively technology-enabled' (p.17). New services that form part of this trend, along with social media, include makerspaces. Weinberger (2012) identifies this as a part of the LIS concept of the 'library as a platform' for different services. However, although a growing phenomenon (especially in the US), support for academic library makerspaces is currently still outside the scope of many university library services. Professional librarians may legitimately ask: why should we have this service in a library? Academic librarian and makerspace service manager Adam Rogers (2016) makes the case that, although maker technological skills may be challenging to many librarians, the ethos of academic libraries and librarians fits well. Roger's positions librarians' ethos as promoting open access, democracy, diversity, education and lifelong learning, which fit well with the makerspace concept. To back up his argument, he cites the influential librarian, mathematician and humanist scholar Dr S.R. Ranganathan (1931). Ranganathan framed five LIS phenomenologically defined 'laws' for librarianship (e.g., books are for use; every reader his or her book). These 'laws', as well as embodying an egalitarian view of getting books to readers, also identify the library as a growing organism:

> The vital principle of the library - which has struggled through all the stages of its evolution… is that it is an instrument of universal education, and

> assembles together and freely distributes all the tools of education and disseminates knowledge with their aid. (Ranganathan, 1931, p.415)

This vision reflects more recent library history worldwide with national and then public libraries appearing around the world in the 1800s, often from royal, monastic and private collections. Thus Rogers argues that, with new tools (beyond books) for creativity and social knowledge production emerging, the phenomenon of the makerspace fits with the purpose of libraries. Academic librarians' skills are also possibly a good fit with supporting a makerspace because 'digital fabrication... is an information process...Some librarians… define it within information literacy, digital literacy or (new) media literacy' (p.2). As the leading university service providing learning spaces that are open to all, academic libraries should consider supporting cross-disciplinary maker services and spaces if there is a perceived need at a particular HE institution. As Rogers notes, 'Makerspaces… surface at the confluence of library strengths: community, technology, and creative learning space. (p.4)' The case is also made by Andrews *et al.* in a 2017 SCONUL report that innovative spaces such as makerspace fit well with academic libraries' mission of bringing users together so they can exchange ideas, learn from each other and the resources and scaffolded support provided. The report reasserts the library's centrality in supporting teaching, learning and research whilst arguing for the need for academic library services to become more proactive in aligning services to the institution by embracing more partnerships. New partnerships could then result in new projects that follow the institutional strategy.

Others, however, are more reluctant to face up to changing environments. Librarians such as McGillis (2016) have lamented the lack of progress found in ten years of recent Canadian HE libraries' history in trying to address key service challenges including technological impact, digitisation and support for new kinds of learners. Working in vertically structured silos and being reticent to try new services are identified as weaknesses as only services 'we' believe are important' (McGillis 2016, p.1) are focused on. The 2017 SCONUL (Society of College, National and University Libraries) report further identifies a mismatch between UK HE library professionals' vision of the future of academic libraries and that of stakeholders, with professional librarians seeing the physical collection as still defining their library and their professional identity in ten years. In contrast, other non-stakeholders are much less sure about the library's future in anything like its current form. Makerspaces are one among a number of potential ways libraries may begin to address current concerns about the relevancy of academic libraries to the evolving academy.

3.3 Historical perspective

3.3.1 The emergence of maker-culture

In keeping with my Cultural-Historical perspective in order to better understand the present and possible futures for the makerspace phenomenon we need to frame it in its historical setting. The origin of the 'Maker Movement' can be seen in the emergence of the similar concepts of 'Hackerspaces' developing in the 1990s and 'FabLabs' from 2001. The three terms are often used now interchangeably (Davies, 2017). Hackerspaces initially developed in Germany in the 1990s as open membership and community operated, not for profit, technology experimentation spaces (usually involving computers, machining and digital art). Neil Gershenfield, at the Massachusetts Institute of Technology's Centre for Bits and Atoms, helped to spread the concept of similar experimental spaces around the world as FabLabs to inspire local citizens to become familiar with digitisation and fabrication processes. 'Makerspace' as a term first appeared in 2005 and has been used to describe spaces where anyone with interest in creating using older or newer technologies could meet together with others of variable levels of expertise in a mutually supportive DIY environment. This DIY and tinkering friendly focus differentiates makerspaces from FabLabs to an extent with their more overtly civic or entrepreneurial focus (e.g., the Fab City Global Initiative emerging in 2014 to support local companies and services in more sustainable circular economies). DIY itself was an emerging 20th phenomenon defined by garages and sheds as home workshops, being a mostly male activity. Makerspace members can use these spaces alone or in collaborative groups on short or sometimes longer-term projects. The term makerspace became popularised by Dale Dougherty's (CEO of Maker Media) *Make* Magazine from 2011 with an emphasis on playful, creative experimentation:

> The origin of the Maker Movement is found in something quite personal, what I might call 'experimental play'...Makers …try and do things even the manufacturer did not think of doing.
> (Dougherty 2009, p.1)

Maker culture is most apparent in America where the 'maker-movement' was supported at government level under President Obama's 'Educate to Innovate' campaign in 2009 when the White House held a 'Maker Faire' on June 18th, 2014. By 2016 over thirteen hundred makerspaces had been established worldwide, a fourteen times increase from the number in 2006, including approximately one hundred in the UK (Sleigh, Stewart and Stokes, 2015). These initially developed in communities, and subsequently museums and libraries. The global extent of the maker movement is apparent through the growth of Etsy.com (an e-commerce marketplace specialising in maker products) which by 2015 had: '15 million artisans across more than 150 countries, with 690,000 new members joining each month' (Etsy.com, 2015, *np.*). The movement incorporates 'Maker Faires' which were started by *Make* magazine to celebrate the arts, crafts and engineering activities emanating from the maker do-it-yourself mindset. The idea of ‘success’ as creating viable or commercial products is not essential to most makerspaces since learning through tinkering and making mistakes is encouraged. However, there have been examples of innovative new technologies that have been created in makerspaces (e.g., ‘Newborn Incubator Helping Save Premature Babies in Rural Villages’ Kraft 2014). This kind of real-world impact shows that makerspaces can be useful socially as well as educationally.

3.3.2 Makerspace research

A foundational research study from the literature on makerspaces is Sheridan et *al.*’s (2014) ethnographic study ‘Learning in the Making: A Comparative Case Study of Three Makerspaces’. This research was carried out in the US on a museum-based makerspace and two membership fee-based community makerspaces. The study positions the emerging phenomenon of makerspaces as being ‘informal sites for creative production in art, science, and engineering’ (Sheridan *et al.*, 2014, p.505). This research draws on the learning theory of Constructionism (Harel and Papert, 1991), which in turn builds on the pioneering work of the clinical psychologist Jean Piaget’s (1896-1980) cognitive development theory of ‘Constructivism’ (Piaget, 1937). As discussed in the literature review part 1, Constructivism’s understanding of learning and knowledge creation proposed an internal cognitive process of construction and constant re-evaluation of mental representations and schema determined by one’s social environment. Although often contrasted with Vygotsky’s more social view of learning and development, Piaget also held that social life was essential to the creation and growth of knowledge (Piaget,1995). Subsequently, Constructionism, developed by Seymour Papert (1991) also introduced in part 1, emphasised the making of material artefacts as a particularly useful psychological tool in learners’ conceptual understanding. Thus, Papert’s Constructionism highlights the importance of a materially creative experiential learning approach to support practical learning aims in which 'the artefact itself functions as an evolving representation of the learner's thinking' (Sheridan *et al.*, 2014, p.507). Sheridan *et al.*'s research found that makerspace learning involved largely self-directed and informal peer to peer teaching and training in Communities of Practice (CoP, Wenger 1991), with no firmly established teacher-student relationship. Statements from participants in the Mt. Elliot Makerspace from their case study suggest the learners' self-identity and assertiveness can be positively strengthened through participation in the makerspace, with a degree of increased self-efficacy being demonstrated among makerspace users (Sheridan *et al.*, 2014, p.518). The relevance and challenges for CoP in building self and group-efficacy in the maker-learning I found in this case study is explored in full in the data analysis chapters of this thesis.

3.3.3 Empowering social agency through technological mastery

A key a piece of research that inspired my own research interests was the Royal Society of Arts (RSA) Action and Research Centre's research report based on a mixed methodology of desk research, data mining, interviews and visits to twelve UK makerspaces: 'We argue that the act of making is one means of regaining mastery over technology – not just because it enables us to be more self-reliant but also because it can boost our sense of agency' (Dellot, 2015, p. 5). Historically, makerspaces are compared and contrasted with other movements thatlook for a better economic and social system through resisting technological advancement, such as the Luddite protests of the early 1800s against the advance of weaving machinery replacing jobs). However, these historical social movements, although emphasising the valueof the kind of individual human skills which are glimpsed in the maker movement, are nonetheless different to the makerspace movement which emphasises embracing rather than resisting new technology and regaining an apparent 'mastery' over technology.

The RSA report highlights self-fulfillment, learning and entrepreneurial opportunities as potential beneficial outcomes from the creative engagement with technology that can occur in makerspaces. Makerspaces are seen as a way of connecting in a more humanistic way of dealing with technology, whereby we can potentially resist the likelihood of more dystopian predictions of our technology-enabled future (as with Frey and Osborne's (2013) prediction that in the next thirty years 47% of occupations will be fully automated). The RSA report outlines positive benefits of makerspaces, including social learning, increased well-being through the creative process, and learning through more traditional scaffolding, including introductory classes for technologies such as 3D printing and Arduino. More inclusive targeted skills-based projects are also highlighted, such as the 'Digital Skills for Women' from the MadLab in Manchester (Dellot, p.27). Thus, the significance of this for Higher Education library and digital services of these findings can be seen in the possibility of helping to meet globally prevalent HE inclusivity and accessibility targets through makerspace services. Although this report was influential in my research interest in exploring the more emancipatory possibilities of maker-learning, it was also useful in starting to see how more idealist maker-learning stances can be problematised as I shall now go on to show.

3.4 Critical views on maker-learning

3.4.1 Problematising technological 'mastery'

A key potential value the RSA report identified for makerspaces is that they support entrepreneurial activities such as 'enabling people to create prototypes of products that can be manufactured elsewhere' (Dellot, 2015, p.28). There is a tension in the makerspace literature between this acceptance of makerspaces as part of neo-liberal market-based structures, and more radical interpretations of the makerspace movement which challenge existing capitalist hegemony (thus encouraging technological mastery as more than just an adjunct for consumer capitalism). For example, Dellot and colleagues (2015) identify makerspaces as being able to foster critical learning about different social possibilities through the opportunity for communities to explore different ways of living that are more focused on ethical production rather than consumption (p.31). Dellot makes the strong claim that makerspaces may be 'a new institution through which to reimagine capitalism' (p.45). This suggestion that makerspaces might help to develop a new form of capitalism echoes one of the future directions of the makerspace movement identified in Chris Anderson's book *Makers: The new industrial revolution.* Anderson proposes that,

> In a future where more things can be fabricated on demand, as opposed to manufactured… you can see the opportunity for an industrial economy that is less driven by commercial interests and more by social ones. (Anderson, 2012, p. 226)

However, writer and makerspace manager Will Holman (2015) presents a more critical view of the possibilities for maker culture whilst referencing Anderson's (2012) argument that the future of manufacturing is in distributed design and production. In contrast, Holman argues that 'conventional manufacturing is still really good at making high-quality and masscustomised products' (Holman, p.19). Significant changes to the ownership of the means of production are predicated on the assumption that the current desktop tools 'will become as easy to use as inkjet printers. And if history is any guide, it will change the world even faster than the microprocessor did a generation ago' (Anderson, p.59). Thus, the extent of Dellot's (2015) proposal that maker-learning leads to technological 'mastery' can be problematised (a theme I further explore in this thesis) on the basis that familiarity with the restricted range of relatively cheap and accessible technologies found in makerspaces may not, at least at present, challenge the more expensive, sophisticated and effective tools that big businesses use for the manufacturing process.

3.4.2 Makerspace and progressive education

Further links to idealistic educational aims are explored through Halverson and Sheridan research that observes a degree of emerging synthesis between progressive educators 'talking about learning as the creation of meaningful artefacts' and 'artists and arts educators [with] long histories of supporting learning in the making across the variety of art forms and media' (2014, p.498). A potential promise of the maker movement they identify is that it can 'democratize access to the discourses of power that accompany becoming a producer of artefacts, especially when those artefacts use twenty-first-century technologies' (p.500). Sarah R. Davies' ethnographic study of hacker and makerspaces across the US also emphasises the horizontal, collective, emancipatory possibilities emerging in makerspace culture through communities where people can meet (not just online) and productively collaborate: 'it is clear that for those we spoke to, participating in hacker and makerspaces was experienced as emancipatory and personally empowering' (Davies, 2017, p.167). Thus, a contradiction can be seen in the research literature to date with the emancipatory, collaborative understanding of makerspace culture and a more self-driven, entrepreneurial interest in their possibilities as per this example: ‘The openness of a shared space, access to social technologies, and community of social support helped members develop entrepreneurial skills and self-efficacy’ (Hui and Gerber, 2017, p.223). The inherent cultural tensions and contradictions in the maker movement are drawn out clearly by Davies: ‘Hacking and making are simultaneously revolutionary and ancient... counter-cultural and anti-consumerist and mainstream business opportunities’ (2017, p.154).

Thus, we can see that without careful service design and support planning for a maker-learning environment in an HE environment, this central tension between the counter-cultural and neo-liberal components of the maker-movement could be imported wholesale into higher education. Given the current dominance of a neoliberal market based HE culture in many countries (including the US and UK), we can see makerspaces in HE potentially becoming uncritical hubs of market culture hooking into the university and students’ finances without providing much in the way of genuine empowerment or powerful knowledge.

3.4.3 Sustainability

Though the RSA report is a positive appraisal of the possibilities with Makerspace, challenges are not ignored. These include environmental issues (e.g., the abundant use and production of plastic in 3D printing), as well as issues around inclusivity including the difficulty of engaging women (Dellot, 2015, p.7). Concern is raised by Dellot (2015) about how ethical makerspaces will be unless strong collective leadership addresses the issue of sustainability with the materials used. More recently the maker movement has seen elements emerge with a strong focus on environmental sustainability. For example, in London’s Maker Mile, set up originally as a Design Festival Route in 2005 (Maker Mile website, 2020), that encompasses various fabricator and maker workshops in East London, the open source project of *Precious Plastic* has been developed (preciousplastic.com, 2020) by Dave Hakkens. *Precious Plastic* reengineers plastic rubbish into everyday essentials such as bowls, cups and tables. Another start up from the Maker Mile, *Opendesk*, allows customers to match furniture found online with the closest fabrication lab where it can be made onsite. This effectively cuts the cost and much of the pollution from the supply chain (Opendesk website, 2020).

Evidence of the issue of sustainability being taken seriously in the maker-movement can also be seen from the report from the workshop at the Machine Room makerspace in London in 2015 that looked at cultivating sustainable developments in makerspaces (Smith and Light, 2016) with approximately eighty makers from the UK and Europe. Best practice was shared with regards sustainable eco-making, upcycling, repair and re-use projects and other contributions to the circular economy. Methods for open-source sharing of best practice with regards sustainability issues included 'projects, testimonies of peoples.. themed meet-ups, analytical reports' (Smith and Light, 2016). More recently further evidence of sustainability being addressed can be seen in the 'ecoMaker' project presented at the 4th ISAM:International Symposium on Academic Makerspaces (Roeder, Klemichen, and Stark, 2019). This German based project is aimed at both educational institutions with makerspaces and the maker community. The project is designed to provide an open-source blueprint for turning makerspaces into eco-friendly product creation centres. Thus, as part of 'Eco Sprints' makers are asked to identify eco-friendly alternatives for each defined part and function of a product or product prototype; for example, an alternative design for a desk lamp with 'an energy saving bulb and a wooden stand' (Roeder, Klemichen, and Stark, p.2 and p.4, 2019). Examples of the 'ecoMaker' design framework being adopted include introduction workshops at the FabLab Berlin (FabLab Berlin, 2020), and as the 'methodological approach at the VINN:Lab (the biggest public makerspace around Berlin)' (Roeder, Klemichen, and Stark, p.5, 2019).

3.4.4 Inclusivity and diversity

Holman (2015) questions how inclusive the maker movement is: 'according to Maker Media's own surveys, the movement is overwhelming male, well-educated and affluent' (p.4). Others ask how women can be encouraged to enter these often-male dominated DIY environments. Faulkner and McClard point out that 'studies indicate that men make up as many as 81% of all makers, a percentage that is similar to the gender breakdown of major tech companies' (Maker Market Study, 2012; quoted in Faulkner and McClard, 2014, p.188). They go on to state that, even if makerspaces can attract more women by including more craft-based activities, there are still social prejudices that privilege technology and engineers over artists or craftspeople in terms of cultural values. Lewis (2015) looks at makerspace literature and observes how possibly unconscious male bias, technical jargon and women's own self-identity may restrict easy participation in these garage-like DIY spaces. Thus patriarchal control may lead to the male domination of typical STEM and computer subjects being culturally reproduced in makerspaces.

Although some makerspaces have adopted a 'STEAM' approach, adding arts and crafts to the mix to try and appeal more to women, it is worth noting that as well as gender stereotyping this does not necessarily address all issues of inclusivity: 'crafting practices, while historically feminised, are not necessarily shared across points of intersectionality, such as race or class' (Barton, Tan and Greenberg, 2016, p.5). Feminist perspectives have illuminated how culture defines who counts as a maker (e.g., Shivers-McNair, 2019). A fundamental criticism of makerspace learning has been put forward by engineering Professor Debbie Chachra who sees maker culture as redolent of traditional patriarchal values, with making placed above the more caregiving activities involved in teaching, constructive criticism and learning support: [maker culture's] 'success... devalues the traditionally female domain of caregiving, by continuing to enforce the idea that only making things is valuable' (Chachra, 2015, *n.p*). However, her identification of the traditionally female domain is itself a stereotype that can be seen as a somewhat limited view of feminine virtues. As well as concerns about gender bias, maker culture can be critiqued in a sociocritical class aware manner as to how 'making' is defined and what it means to make in a particular cultural context. Feminist scholar Krystin Gollihue (2019) explains how a maker culture framed by electronic practices in middle class, academic and corporate environments ignores a whole cultural history of non-academic shared learning and making in agricultural settings, using her farm upbringing as an example.

Some frameworks for makerspaces as educational tools have tried to address these issues of inclusivity. For example, Hira and Hynes' (2018) conceptual framework of 'people, means and activities' when designing makerspaces and makerspace learning allows for situated contextual design to challenge the prevalent narrow middle class, patriarchal, white maker culture: 'We do not suggest who is Making, what is being Made, what is being used to Make, or where the Making is happening' (p.9). Many in the maker movement reject the idea that maker culture is fixed in a narrow middle-class patriarchal mode: 'I am hopeful that instead of rejecting the term, as Chachra does, educators can instead reimagine and transform it to support imaginative young people' (Mirra, 2015). More inclusivity has been achieved in some makerspaces through the inclusion of traditional arts and crafts skills as well as electronics (e.g., Curtin University Library in Australia: Wong and Partridge, 2016, p.154). Although stereotyping different types of making as female, the introduction of arts and crafts does at least counteract the primary and sometimes narrow focus within makerspaces on digital making and could be seen as inclusive if males are encouraged to engage with these traditional types of making along with females.

3.4.5 Critical making and maker culture

The neoliberal versus emancipatory tension mentioned can also be seen in the ethos of sharing open-source software in the early maker movement being compromised in many respects by increasing market forces. Sales of goods on Etsy reached a turnover of about 2.4 billion USD in 2015 (Etsy.com, 2015). In his monograph *Radical Technologies: The design of everyday life* the American writer and urbanist Adam Greenfield notes how the original open-source ethos within maker culture has been challenged through neoliberal market opportunism: ‘It was MakerBot co-founder Zachery Smith that complained most prominently when the company announced… its products would no longer be openly specified and licensed’ (Greenfield, 2017, p.105). Driscoll (2017) points out that Make has received a grant from DARPA (Defence Advanced Research Projects Agency), which has a history of mining DIY/hacker/maker cultures for talent. This fact in addition to the ten million dollars granted in 2012 from DARPA to TechShop to ‘establish new makerspaces that could help the agency with its ‘innovation agenda’’ (Morozov, 2014), shows how maker innovation can be co-opted in ways makers are barely aware of. The focus in many makerspaces on robotics and sometimes drone technology could lead to exploitation for military purposes, again challenging any progressive aims within maker culture.

The tendency of the makerspace movement to reinforce the status quo is noted by many researchers. Waldman-Brown *et al*. (2015) argue that makerspaces are a mostly middle-class phenomenon that needs to connect with 'grassroots artisans' for a genuinely inclusive approach. Regarding the potential for replicating environments which are inherently discriminatory against working-class students and students of colour generally, Vossoughi, Hooper and Escude (2016) recommend that makerspace research design include principles of equity-orientated research to resist the branded technological/economical focus of much maker culture (p.227). STEAM (STEM + Arts) is also criticised to an extent as an illustration of the 'ways arts education may be supported in so far as it contributes to scientific and economic initiatives' (p.226).

However, it is *possible* to challenge a narrow view of maker culture and argue that emerging technologies and scientific practice can in effect underpin inclusive non-commercial (in this case, artistic) endeavours. For example, UK based Academic Librarian/Digital Services Developer Gerard Helmich supported a senior lecturer in Fine Art, Clair Chinnery, in the production of blown-up 3D models of milk teeth to be incorporated into an artistic display to be shown at UK universities. The collection was part of a reflection on significant moments from women's lives, forming a key component of the 'Within and Between: Women/Bodies/Generations' conceptual art exhibition by Chinnery, Janice Howard and Lisa Richardson (Richardson, 2019). Here we can see technoscience in the service of a feminist art project (helping to form a sculpture showing how women's lives often become sacrificed to the needs of nurturing the next generation, while witnessing the demise of the previous one).

The idea that has particularly interested me as a key to understanding how academic libraries might cultivate more inclusive cross-disciplinary learning is ‘Critical Making’ as previously defined in part 1 of the literature review (Ratto, 2016). ‘Critical Making’ and evaluation have been built into some maker programmes in higher education in an attempt to take a sociocritical stance towards achieving a conceptual understanding of the material world in the embodied making process:

> Perhaps critical making is most adequately defined as a simultaneously constructionist and diffractive process of learning: a tacit, material, and conceptual transformation. (Ratto and Hertz, 2019, p.14)

Gollihue (2019) argues for an expansion of Critical Making’s conceptual focus on things: ‘While a study of critical making necessarily requires attention to things, it is not enough to *only* concern ourselves with things. Instead, things must be in relation to the people that made them, the history that surrounds them, and the cultures and practices they represent’ (Gollihue, 2019, p.3). This broader cultural and historical perspective is one I share, and a reason for my Cultural-Historical Activity Theory (CHAT, Engeström, 1987) framework I shall go on to explain in the following chapter.

3.5 Makerspaces in universities

3.5.1 Opportunities for authentic learning?

The potential value of makerspaces in higher education has been noted in recent years by the NMC Horizon Report for Higher Education, while research on makerspaces in universities is a currently evolving field. For instance, Wong and Partridge’s (2016) qualitative study of websites from Australian universities found twelve of the forty-three universities observed hosting makerspaces, as well as ‘pop-up’ makerspaces being employed by some university libraries to explore the viability of creating a makerspace. Although the principle of making in a community environment was found in all cases, different universities use their makerspaces to focus on varied kinds of learning. These include exposure to new technologies and developing related skills, co-locating researchers, innovators and entrepreneurs to encourage technology transfer, focusing on student-led learning interests and helping students to convert ideas into small business opportunities (p.145). Makerspace staffing was found to be carried out by specialist staff, student maker clubs, a combination of these groups or library staff (p. 147) with the following typology of activities given: research projects, coursework projects, personal projects, collaborative projects, workshops and makerspace club activities (p.150).

Makerspaces are often found in Engineering departments, aligned with learning programmes that employ project-based learning and active learning. Research by Saorin et al. (2017) at La Laguna University showed positive outcomes for fostering ‘creative competence’ in engineering students taking part in a makerspace educational activity involving the creation and individualisation of dolls using 3D printing and scanning, which allowed student groups to find different solutions to problems encountered in the creative process. An ‘Abreaction Test of Creativity’ inductive graph test (de la Torre, 1991) was used, and a survey of student perceptions of learning gains showed activities with digital editing tools and three-dimensional printing ‘are valid for the development of creative competence’, whilst perceptions of students’ improvement in their activity were high ‘with values above 3.5 out of 5’ (Saorin, 2017, p.1). Improving students’ creativity and innovation is an aim on many courses across multiple disciplines, thus as a central learning space, academic libraries may consider findings such as this of interest to planning new learning spaces open to beyond just STEM students.

Wilczynski and Adrezin (2016) observe that merely converting a lab into an instant ‘makerspace’ is unlikely to encourage the necessary mix of collaborative (including peer to peer) instruction, self-directed and innovative, project-driven learning that marks a ‘makerspace’ as being different from most classroom or lecture-based learning. However, merely replicating non-academic makerspaces may also not be sufficient to install a makerspace as a beneficial higher education learning environment. The need for careful design of a new academic makerspace is emphasised by Shane Farritor (2017), an engineer who outlines suggestions for creating makerspace models that encourage innovation and a culture of self-motivated learning, rather than a more creatively stifling focus on grades and degree requirements. Ideas suggested by him include allowing students time to tinker and explore, opening the makerspace to a diversity of ideas from different disciplinary use, locating the space in an intersection of different disciplinary learning environments open to all, hosting tools for art as well as engineering, and looking at the possibility of makerspace membership beyond university-only use.

Pedagogical interest in higher education makerspaces is starting to emerge in the Academy, but as yet there is not much detailed research. The most significant to date has been Kjallander *et al.’s* (2018) study that looks at three different Nordic initiatives in Teacher Education (TE) to see how makerspaces can bridge informal and formal learning settings. The core aspect of the maker movement of interest to didactic design was found to be ‘authenticity’, as maker-learning builds upon the interests, enthusiasm and engagement of individual students’ real-world interests through creative maker activities. Lombardi (2007) identified the following characteristics of ‘Authentic Learning’ (as introduced in part 1 of the literature review):

- Subject of Learning: Real-world relevance, ill-defined problems, multiple source and perspectives.
- Process of Learning: Sustained investigation, collaboration, reflection (metacognition), interdisciplinary perspectives.
- Polished products, integrated assessment, multiple interpretations and outcomes.

Although maker-learning can fit this model of learning, the role of ‘real-world relevance’ and ‘polished products’ in the experimenting and tinkering-friendly culture of the maker movement is not always apparent. Thus, the extent of the real-world relevance of their maker activities became one of my critical questions for students. Kjallander *et al.* (2018), as well as arguing for HE makerspaces as opportunities for authentic learning, also call for educators to recognise how formal education can help inclusivity in maker-learning through creating maker-learning activities across disciplines.

3.5.2 Academic Library Makerspaces

Makerspaces may be a natural fit within engineering courses where the importance of space for experiential learning, problem-solving and the creation of prototypes are already an assumed baseline requirement for pragmatically effective learning. Yet, the library as an open, welcoming, non-pressurised third space has an opportunity to collaborate on new makerspace projects that create an open access, cross-disciplinary, social learning space. Creative cross-disciplinary possibilities for library makerspaces were put forward by Barniskis (2013, p. 9) who argues that ‘a makerspace can support any type of creative endeavour, depending on the people who belong to the space’. Although encouragement for starting a library makerspace is often found in the literature (e.g., Burke, 2015), pragmatic difficulties are also highlighted. For example, Kurti, Kurti and Fleming (2014) highlight the challenges of creating a makerspace from scratch: 'some policies will stand in the way, space will be hard to obtain, and the budget for tools will be almost nonexistent' (p.7).

Despite the challenges, there is an evolving interest in the literature with the possibility (and increasing emerging reality) of academic libraries hosting makerspaces: 'Given the interdisciplinary nature of most academic libraries, they remain open to the whole campus community. It can be argued that they are the best place to have a makerspace on campus' (Burke, 2015, p.504). Barrett *et al*. (2015) also highlight the advantage, in terms of broader access, of creating a makerspace in an academic library as a central location for multidisciplinary activity. Their US-based study showed this location choice was increasingly becoming a reality: 'Perhaps the most common location where maker spaces are housed on college and university campuses is the library' (Barrett et al., p.14, 2015). Wong and Partridge's (2016) Australian HE study observes how, although makerspaces are most often seen in engineering and design faculties, the interest in academic libraries hosting makerspaces was apparent, with the opportunity to provide access to new technologies and encourage collaborative learning in a cross-disciplinary setting. It is a new challenge to many information professionals to scaffold meaningful learning objectives within what is often positioned as a Constructionist learning environment free from too much pedagogy or directed support. Yet, without any support at all, students adopting a purely DIY approach to making risks working in an environment with many people often repeating the same mistakes: 'DIY enthusiasts could do better in learning from the past without discovering bad ways to solve problems' (Hsu, 2012).

3.5.3 Academic library makerspace case studies

As discussed in Chapter 1 most of the academic library makerspace research to date is based in North America where the maker movement originated and is at its strongest. There often seems to be faculty interest in the educational value of these spaces: ‘Partnership with faculty also was a common practice among interviewees, with five of the seven [cases in our study] attributing faculty partnership to their success’ (Benjes-Small et al., 2017, p.434). Links to the wider maker movement and culture are sometimes apparent: ‘While academic library makerspaces tend to target student users, reaching out to non-student makerspaces and maker communities was viewed as a valuable exercise’ (p.434). As mentioned in the introduction, academic libraries in the UK have only seen a few makerspace examples emerge so far; for example, as mentioned in Chapter 1, Edinburgh University has an established makerspace.

A case study from DeLaMare Science and engineering library at the University of Nevada Reno libraries (Radniecki and Klenke, 2017) shows how an academic library service has started to address the particular service changes required to successfully host a makerspace, through providing skills and education support. As the authors point out, the potential for makerspace innovation and collaboration is dependent on users’ education and skills in the required use of available tech (Radniecki and Klenke, 2017, p.15). The DeLaMare library service repurposed existing library instruction models to include teaching on 3D modelling and scanning, design and intellectual property. However, challenges were found here. Despite the high demand for one-to-one support, there was a low turnout for workshops, which the authors concede is not the case with other academic makerspaces they have benchmarked.

Further informative academic library makerspace case studies in the LIS literature from North America show how many have developed or are trying to develop from essentially 3D printing services. Crum *et al.* (2017) describe how Northern Arizona University's successful 'Makerbot Innovation Centre', partnering with faculties and building connections with local entrepreneurial activity mainly around 3D printing, is looking to expand to include other older and emerging technologies (e.g., sewing machines and laser cutters). Their ethos is: 'anyone can create, anyone can invent, and anyone can solve difficult problems in new ways if they have access to the knowledge and tools necessary to bring their ideas to fruition' (Crum *et al*., p.8). The potential challenges and tensions of trying to expand the University of Maryland's makerspace service are highlighted in Horbol and Tobery's (2018) case study outlining how the makerspace operators attempted to find a permanent home through three stages: one a space that was too small, another with inadequate ventilation and finally finding an adequate space for more event and instruction activities. Other challenges beyond space requirements in creating and expanding an academic library makerspace service, as identified by Lee (2017), included the cost of new technologies, how the space will be governed and shared, training staff on new technologies, providing enough staffing for opening hours, negotiating potential territorial tensions between library staff and faculty, and amassing student data on how successful the makerspace is in meeting agreed aims.

Research on the current trends and goals of New England College and Research Library makerspaces (Davis, 2018, involving an online survey and phone interviews) found common objectives of promoting new hands-on participatory literacies, providing open access to new technologies in keeping with libraries' historic goal of providing access to the tools of knowledge, and fostering a cooperative ethos of making across disciplines to meet curricular goals in science and arts (STEAM): 'Above all, respondents focused on the pedagogical opportunities on the one hand, and the potential for outreach and social justice on the other' (Davis, 2018, p. 108). The potential diversity of equipment and services in Academic Library makerspaces can be seen as a natural evolution to particular institutional needs for pedagogical innovation. As Mathuews and Harper argue (2018), each makerspace needs to tune in to particular institutional contexts through pre-making activities and post-making activities to create a dynamic multidisciplinary maker environment. Thus, the 'development of makerspaces should not focus solely on technology and the physical act of making, but... also... collaboration and ideation… presentation and critique' (Mathuews and Harper, 2018). As I shall show this focus on discussion, reflection and critique in maker-learning is also shared by the academic research participants in this case study who use the makerspace as part of their pedagogical approach.

Passehl-Stodart *et al.* (2018) show the possibilities of developing within library service collaborations, as well as outreach activities, between two departments of the University of Idaho Library. Special Collections and Archives and the Making, Innovating and Learning Laboratory were involved in the 3D printing of archive material (namely a student-created statue from 1924 that was the first embodiment of the University of Idaho mascot 'The Vandal'). These outreach activities enabled the special collections team not only to learn about the challenges of 3D scanning and printing cultural objects but inspired them with new ideas about the 'value of special collections materials for outreach' (p.147). Other possibilities for collaborative learning across boundaries which incorporate makerspaces are identified by Nichols *et al.* (2017) in terms of supporting entrepreneurs and digital humanities and digital scholarship at the University of Arizona Libraries in Tucson. 'Digital humanities centers support scholarship… enabled by digital methods as well as scholarship about digital technology and culture' (p.363). Nichols *et al.* (2017) also argue that the makerspace offers an unprecedented working space for digital humanists who no longer have to buy their own technology or reach out to other departments for innovative projects.

They give the example of a Virtual Harlem project which focuses on community in the 1920s and 1930s during the Harlem Renaissance. Thus, we can see a more emancipatory view of (critical) maker-learning can look to bring historical events to life in innovative ways.

3.6 Knowledge gaps and further questions

The research and grey literature indicate that each academic library makerspace needs to tune in to the particular cultural environment of the hosting university. This fact renders simple generalisations to other academic library makerspaces problematic. However, there is still much to be learned from more in-depth case study research on the development of these new learning environments as potentially embodied, experiential learning spaces where a critical engagement with new technologies can occur in intersecting communities of practice reaching across disciplines and curricula to address real world issues. There are significant challenges to creating a worthwhile makerspace in an academic library as outlined in the literature reviewed above. As identified at the start of this thesis, the professional interest at the core of my key sub-questions was in the evolution of the case study service through initial tensions, including different user group needs, to create an inclusive, innovative cross-disciplinary environment. My thesis examines gaps in the current literature around how academic library makerspace services have evolved to incorporate maker-learning spaces that may create tension or contradict existing ‘traditional’ services, and insights into how an inclusive approach to the sometimes-radical differences in learning objectives across disciplines may be addressed. Issues to be addressed include how the middle class, white, male dominated STEM focus of maker-learning can be challenged in this evolving learning space. From discussion of the findings, I look at how a more critical model for maker-learning can be developed to further evolve the more emancipatory possibilities within a movement for critical maker-learning in HE. Thus, I address this project through four big questions which I go on to explore in depth in this thesis:

- How did the library makerspace service evolve beyond initial challenges and tensions to aim to support expansive, inclusive, embodied cross-disciplinary learning?
- How are any apparent contradictions between the learning objectives of different user groups addressed in the library makerspace service?
- Is the lack of diversity in STEM challenged by this library makerspace service?
- What are the main tensions and contradictions that need to be addressed to further scaffold critical maker-learning in the library makerspace service?

3.7 Summary of Chapter 3

This chapter has looked at critical views on makerspaces, the maker movement and maker-learning. It then problematised specific aspects of maker-learning, particularly makerspaces' potential to provide technological 'mastery' in a meaningful and inclusive way. I have drawn out the developing potential for maker-learning within HE as sites for authentic learning if the right critical design and scaffolding for useful real-world learning affordances is implemented. The chapter looked at the emerging literature on university makerspace and academic library makerspaces in particular. I have identified significant gaps in knowledge from topics introduced in the literature review chapter that had found limited existing literature, which I go on to explore in this thesis. In the next chapter, I will explain my use of Cultural-Historical Activity Theory (Engeström, 1987) as my theoretical framework to uncover the learning potential and inherent tensions in maker-learning as the maker movement evolves further in HE academic library services.

Chapter 4 Theoretical Framework

4.1 Introduction

The "third generation" of Cultural-Historical Activity Theory (Engeström, 1987) has strong explanatory power for my case study, as it can be applied to professionals leading organisational change, as with scaffolding of the new services around maker-learning in my case-study library. The CHAT framework has enabled me to focus on the organisational evolution in the library makerspace service through the relationships between library staff, academics and students, their tools and goals in using the library makerspace and the tensions that have had to be overcome for the service to expand and succeed such as it has. This overarching framework thus enables me to look at how the professional and academic scaffolding enables and supports the maker-learning I have described through the concepts introduced in Chapter 2. From the CHAT perspective, learning (through the appropriation and use of cultural tools, practices, and norms in collective practice) arises from participation in communities in 'joint, goal-directed activity' (Turpen and Finkelstein, 2013, p.45). In the first section of this chapter, I give a brief overview of CHAT. The next section looks at the limitations of a CHAT framework while the final section looks at how these limitations can be mitigated by Anne Edwards' sociocultural/cultural-historical relational concepts (2017).

4.2 Overview of Cultural-Historical Activity Theory

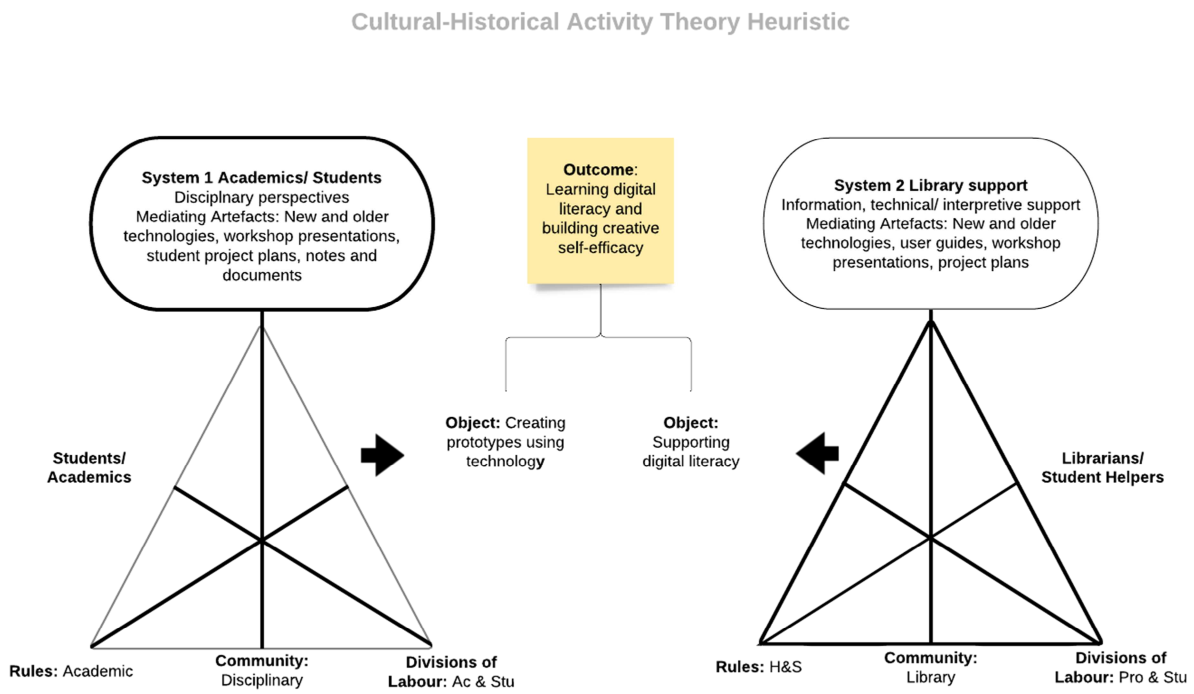
Cultural-Historical Activity Theory is a term coined by the psychologist Michael Cole to describe the cultural approaches to mind in Russian psychology he found when reading texts by and conversing with the neuropsychologist Alexander Luria, a close colleague of Lev Vygotsky. Vygotsky and Luria's work was primarily concerned with conceptualising consciousness, looking at how minds are shaped socially. Their logical-historical answer to what they saw as the prevalent false Cartesian duality of mind and world in much psychological theory was mediation: the idea that we take on and work with the ideas that are valued in the social practices we are born into (Vygotsky, 1978). Vygotsky's outlook was also informed by Marxism's materialist interpretation of historical development, and his interest in how we use conceptual tools not just to understand but also to change the material world. Vygotsky observed how higher mental functions could develop through social and material interactions which generate the habits of mind of a particular culture. These higher mental functions include speech patterns, written language and symbol systems, including those from material artefacts that are absorbed through a process of internalisation from the social to the individual, for example road signs which convey particular meanings without words.

Cultural-Historical Activity Theory as modified and developed by educational psychologist Yrjö Engeström (1987) advocates the study of artefacts as integral components of human functioning and expands the original triangular representation (subject - mediating artefact/tool - object/outcome) of activity to look at the macro-level of the collective or community, its rules and divisions of labour (taking Vygotsky's concept of the Zone of Proximal Development (ZPD) from an individual to a group level). Examples of CHAT-based research influential on this thesis included Engeström's work with academic libraries: two case studies at the University of Helsinki where his boundary-crossing 'knotworking' concept was developed. Through his 'Change Laboratory' methodology, Engeström looked at how academic librarians could support research through short term mini projects and change to different groups ('knots') in a flexible manner; (Engeström, 2012). Engeström focused on the importance of analysing the interactions and possible tensions/contradictions in an activity system, highlighting how contradictions within activity systems can be the driving force for change and development (Engeström, 1999).

CHAT is a lens for looking at local cultural evolution through individual and collective agency. Although influenced by Hegelian dialectics based on ‘contradictions’ in systems being resolved at a higher level of understanding, and subsequent Marxist class-focused historical materialist dialectics, it does not share their expansive**,** society-wide, teleological outlook. The focus of a CHAT framework is on the local and how collective action concerned with a examining a problem space of intersecting activities can bring about the development of positive change. CHAT frames organisational change through a focus on local history and culture and shows how individuals collectively overcome ‘tensions’ in emerging systems in aiming to create new environments. As Engeström writes, **‘**In my analysis, dialectics is the logic of expansion. And expansion is essentially a social and practical process, having to do with collectives of people reconstructing their material practice’ (1987, p.242). CHAT thus enables a focused, contextual look at the complex educational environment, service elements and learning resources offered by a modern academic library service. CHAT has enabled me to show how makerspaces might challenge academic library service models by having technologies, as a new kind of ‘learning resource’ both ‘contradicting’ and creating ‘tensions’ with the prevalent book and journal-based learning model, available to students in an academic library space.

4.2.1 CHAT as an explanatory tool: initial heuristic diagram

With the third generation of CHAT, Engeström provides an explanatory framework including statements about the methodology, which he calls ‘principles’. These principles are not just for understanding complex interrelated activity systems, but also potentially act as intervention tools by which research participants can reflect on the internal contradictions or double binds found through the use of the CHAT model and look to collectively create new models, actions and activities. However, my aim here is to use CHAT primarily as an explanatory rather than interventionist tool for a case study on an emerging phenomenon, which can act as a prototype to stimulate thought on strategic planning in my own and other academic library environments. The below CHAT diagram based on my initial makerspace research (Curry, 2017) is a heuristic for illustrative purposes:



As we can see in the above diagram I have positioned two systems of activity (academics and students and the scaffolded maker-learning support offered by the library service) around the activity in the makerspace with different perspectives on rules, community and divisions of labour which all have the potential to create tensions and contradictions in a problem space to be worked on between the object of activities and desired outcomes. Tensions could include how the library service responds to the multiple ways different academic perspectives would like to see the makerspace used, such as those between the practical engineering focus and demand for more high-tech equipment and the more critical, inclusive and humanistic concerns of the English department at the case study site I will explore in this thesis. Engeström (1987) proposes five principles for CHAT research, the first being positioning the activity system as the unit of analysis. The second is concerned with the multi-voiced (dialogic) nature of the communication in the interacting systems. This principle accepts the complexity of the Russian philosopher and semiotician Mikhail Bakhtin's view of individual voices existing in a social milieu where meaning is created through an ongoing process between individuals, rather than being a 'static entity' (Wertsch, 1991, p.52). Bakhtin's thought is, of course, primarily focused on writing, written text and speech whereas CHAT incorporates embodied action and non-verbal communication, as well as multi-modal sign and tools in human dialogue with materiality. For Engestrom, 'Activities are mediated by multiple modalities, from bodily movements andgestures to pictures, sounds, tools, and all kinds of signs' (2009, p.308).

The third principle Engeström highlights is historicity, which prompted my overview of the cultural-historical context of makerspaces in the Literature Review (Chapter 3). This is an important explanatory tool for focusing in detail on the wider reality which influences the particular case being researched. As well as looking at the broader emergence of maker culture and how this manifests in the academic library makerspace context, Engeström's approach enables me to apply what he calls a 'radical localism' (1987). My case study looks very closely at the particular culture of the higher education institution in question and the library service, in particular, to understand how services have emerged historically in this context. Engeström's fourth principle advocates the examination of contradictions and tensions as a source of change between aspects of the activity system. The fifth principle is to use the analysis of the tensions and contradiction to explore the possibilities for expansive transformation of the activity system. In this thesis, for example, I am concerned with tensions and contradictions that arise from conflicting disciplinary, professional and academic understandings of what maker-learning could/should entail. As Wertsch highlights:

> In most cases mediated action cannot be adequately interpreted if we assume it is organised around a single, neatly identifiable goal. Instead, multiple goals, often in interaction and sometimes in conflict, are typically involved.
> (1998, p.32)

My makerspace research forms part of an ongoing conversation about the future direction of academic library services. A significant part of the appeal of engaging with CHAT as a theoretical framework is its focus on the creative possibility of collective transformation, accepting that any kind of expansive developmental change is never easy or predictable. Engeström does not imply that progress is always a smooth linear process or guaranteed in any way. Resolved tensions can create new activity systems with newly emerging tensions and contradictions. Thus, I will analyse the newly emerging tensions around inclusivity, sustainability and cross-disciplinarity and other sub-themes from my case study and offer some thoughts on how they could be resolved in my conclusion.

4.2.2 Limitations of the CHAT framework

Engeström's CHAT has been criticised for simplifying the complexity of Vygotsky's legacy and the differing ambitions and philosophical perspectives of 'Activity Theorists' such as Aleksei Leontiev, Alexander Luria and Evald Ilyenkov into neatly bounded evolving historical generations. For example, philosopher of education David Bakhurst (2009) defines two strands of the activity-theoretical tradition**:** firstly, 'those who see the concept of activity as a fundamental category that is key to understanding the nature and possibility of mind' best exemplified by Ilyenkov; and secondly, those who like Leontiev, model activity systems not just for understanding but practice**.** As Bakhurst explains: 'Activity theory in the second sense is, among other things, a way of modelling organisational change' (Bakhurst, p. 205). Bakhurst cautions that researchers have to be aware of the limits of the model and 'look for 'contradictions', not just within the subject matter the model discloses, but 'between the model and that very subject matter' (p.207). This is sound advice for employing most theoretical frameworks, as no epistemological position is unchallengeable as a complete and exhaustive ontological picture and CHAT can become system focused at the expense of understanding the lived experience of individual perspectives. Thus, in Chapter 7 I move beyond the CHAT framework to explore the ontology of maker-learning found in this case study.

As mentioned above looking for expansive collective transformation through engagement with 'contradictions' in systems can be seen as a localised interpretation of Marxist materialist dialectics and ultimately Hegelian dialectics. For Hegel, individuals often act according to custom. Still, they can become self-conscious and aware of their habits, leading to a discomforting realisation of tensions and internal contradictions in their habitual behaviour. These tensions can then be overcome by applying reason to break habits and choose a new way of being: 'For Hegel, dialectics was the form of thought that included the process both of elucidating contradictions and of concretely resolving them at a more profound level of understanding the object' (Engeström, 1987, p.230). Engeström highlights the importance of the Hegelian notion of dialectics as a historical and logical method which was later adopted in Marx's materialist socio-economic class-based dialectics. However, Engeström also foregrounds the limitations of Marx as primarily a dialectics of solitary thought apparently leading to collective action, rather than a social process involving the transformational power of group-based practical reconstruction. Thus, Engeström deliberately *expands* the scope of his dialectics beyond the individual but *limits* it to more empirically practical and realist local-based systems to be analysed. This 'radical localism' thus looks for a collective responsibility at a local level allowing for genuine cultural and material development. I would argue a focus on the local is a pragmatic move in our post-modern condition, so afraid of grand theories given the tragedies of twentieth century and more-recent extremism. Afterall, it was the crude 'grand' theorising of extreme right and left in the twentieth century that saw profound thinkers such as Darwin, Nietzsche and Marx have their ideas bastardised in new forms of terrifying authoritarianism. Thus, this thesis accepts the importance of the balance between looking critically at the local whilst keeping broad cultural structures in mind and offers insights that will need to be interpreted in a non-dogmatic way in different cultural contexts.

4.3 Cultural-Historical Theory's Relational Turn

A key concept with Cultural-Historical Activity Theory is that 'thinking occurs as much among as within individuals' (Cole, 1996, p.43). Thus knowledge established collectively as part of activity systems in 'distributed cognition' is 'collectively shared among the community through the use of cultural artefacts' (Ramanair, 2016, p.127). Although this is a position I accept, it is important not to 'over socialise' the individual through a CHAT lens to the extent that his or her agency becomes apparently irrelevant in the broader collective system. As Bakhurst notes 'the choice before us is not to conceive minds *either* as atomistic, self-contained and self-sufficient mental worlds *or* as shifting constructs of discursive forces' (2011, p.45). In order not to lose sight of individual agency through a CHAT lens, theorists have added their own 'patches' to CHAT such as the theoretical notion of the self as a 'leading activity' advanced by Stetsenko & Arievitch (2004), who 'emphasise that [the self] is constituted by the ways in which we "do" and perform, rather than have, a self' (p.494).

To get beyond the limitations of relying exclusively on Engeström's predominantly system-based approach, and to provide insight into how research participants work across professional boundaries I have also employed the concepts of 'relational agency', 'relational expertise' and 'common knowledge' as conceptualised by cultural-historical educational theorist Anne Edwards (2012, 2017). She describes how successful professional cross-practice work is dependent on respecting and understanding the standpoint of others ('relational expertise', Edwards, 2017), and taking actions with others ('relational agency', Edwards, 2017) mediated by the 'common knowledge' (Edwards, 2017) of what matters to each participating professional from their values and moral commitments 'paying attention to relationships and trust in the expertise of others and the quality of the resources, both conceptual and material, that they can bring to bear on problems.' (Edwards, 2010, p.104)

This relational turn in Activity Theory does not necessarily negate Engeström's more system-based approach but adds another important dimension whereby the relational agency between professionals and professional groups can be analysed as a core component of successful work in sites of intersecting practice. The relational concepts thus help to explain the additional form of expertise (beyond the more obvious ones within professional technical practice) that makes it possible for expanded understandings between different professional communities and divisions of work, when addressing work-based problems as objects of joint activity. In supporting an academic library makerspace, librarians will often be working with academics and other professional staff who have their own particular professional culture and view of what matters (and as this thesis goes on to show, different disciplines can have very different perspectives of the potential value and use of emerging maker technologies). Common knowledge is concerned with how professionals can develop an understanding of different motives in a system of distributed expertise so that they are ableto build collective agency and 'strengthen purposeful responses to complex problems' (Edwards & Kinti, 2010, p.134). There was much situated understanding to be explored at this intersection of professional cultural boundaries in the North American library service thatwas the focus of my research.

4.4 Summary of Chapter 4

In this chapter, I have shown how I am using the explanatory power of Cultural-Historical Activity Theory (Engeström, 1987) for my case study as an overarching framework that can incorporate the complex tensions found in supporting the different kinds of maker-learning through the domains of learning theory I introduced in Chapter 2 (sociocultural, experiential, embodied and critical). The limitations of CHAT are also examined, in particular, how individual agency can get lost in the analysis of system-based change. I then go on to show how Anne Edwards' relational concepts (2017) have enabled my theoretical framework also to include analysis of the cross-practice work essential for organisational change, where individual understandings of the professional values-based perspective of others enables cultural change to happen. I will now go on to show in the following chapter how I have built the methodology and methods for this research to make sense within this theoretical framework.

Chapter 5 Methodology

5.1 Introduction

This chapter outlines my paradigm and justifies the methodology I used for this research. This involves concentrating on the methodological implications of my theoretical framework and paradigm in terms of focusing on specific areas of interest, and the methods required for my data gathering. I present and justify my data analysis approach in relation to the literature on established research methods and how the methods are chosen to connect to my theoretical framework. The key sections of this chapter are therefore: Paradigm; Justification for, and outline of, my CHAT based case study; Methodology; Methods; Chapter summary.

5.2 Paradigm

As outlined in my theoretical framework, I have contributed to knowledge through building on CHAT using both Edwards' theory and my critical perspective and interest in Critical Information Literacy introduced in Chapter 2. The overarching CHAT framework emphasises the possibility of collective, expansive, dialectical practical change undertaken through both individual and group agency. Conventional material reality is shaped and potentially reshaped through culture, and critical thought can be employed to try and change things in material reality towards mutually beneficial goals - as with the evolution of the case study makerspace service. My paradigmatic position can be described as 'Socio-Critical Realism', a term I have created to express a critical perspective that understands culture as *the* crucial element in humanity's evolution to higher-order thinking. As the psychologist and neuroanthropologist Merlin Donald aptly says, the 'ultimate irony of human existence is that we are supreme individualists, whose individualism depends almost entirely on culture for its realisation'

(2001, p.12). The paradigm of Socio-Critical Realism positions collective effort based on productive relational understanding and practical material change as the only way to make significant cultural-historical change.

Although this social constructivist position invites an interpretivist paradigm with a degree of epistemological pluralism, it can still be considered realist ontologically in the sense that humans have multiple viewpoints on a shared material reality, such as that of working and learning in an academic library makerspace, rather than living in different ‘realities’. Research on our shared material reality benefits from different perspectives on established facts including from science and social science, including in educational research. While ‘hard science’ concentrates on the objective reality of things, sociocultural science researches ‘the totality of forms in which human life is realised’ (Cassirer, 1961, p.84). Piagetian and Vygotskian educational theorists have often clashed over the extent of the importance of sociocultural interaction in the learning process, but this ignores Piaget’s theorising about the significance of social interaction in the learning process: ‘Human knowledge is essentially collective and social life constitutes an essential factor in the creation and growth of knowledge, both pre-scientific and scientific’ (Piaget, 1995, p.30).

My position of social-critical realism accepts a degree of human agency within a sociocultural context, with the interpretation of actors expressing their subjective and intersubjective experience. This framing means that a scientific theory of mind cannot simply ignore cultural influence, as the cultural psychologist Jerome Bruner (1915-2016) highlighted:

> Cultural psychology surely does not rule out ‘reality’ in any ontological sense.
> It argues (on epistemological grounds) that ‘external’, or ‘objective’ reality

> can only be known by the properties of the mind and the symbol systems on which mind relies. (1996, p.12)

Although I consider myself to be both ‘critical’ and a ‘realist’, my research design also denies the need for the entangled language games and near determinism of the ‘causal mechanisms’ found within ‘Realist’ metaphysics such as that of Critical Realism (as developed by Roy Bhaskar 1944-2014). From my realist-sociocultural position, ‘critical’ discussions and arguments must always be based on an individual cultural or political position, after an attempt at non-biased research and understanding. I do not try to claim there is a normative scientifically established objective perspective available that incorporates human values. However, I acknowledge the need for an analysis of the value systems in play from my critical perspective. As Michael Young puts it, ‘Whereas recognising the sociality of knowledge without its reality can lapse into relativism or dogmatism, a focus on its objective reality without recognising its sociality can become little more than a justification for the status quo’ (2007, p.71).

My realist socio-critical position accepts that research undertaken from other paradigms can also be of value, as multiple perspectives on a multi-disciplinary research object such as a makerspace can be enlightening. All paradigms are drawn up in a particular sociocultural moment by researchers, and the overarching episteme of distinct cultural-historical periods may become more apparent from a future historical perspective than they were at the time of the research. Thus, the understanding of social reality can advance through dialectical tensions and debates between research traditions as well as from the dialogic understanding within them.

5.3 Justification for, and outline of, a CHAT based case study methodology

My reason for choosing the interpretive case study approach is that the phenomenon of makerspaces in academic libraries is yet to emerge strongly in the UK. I found the US had some fast-evolving academic library makerspace services, and I was pleased to secure the agreement with the US university's library service that is the basis for my case study. Having established my research focus on academic library makerspaces and reviewed the available literature to date, it became apparent there were not many well-established academic library makerspaces even in the US. The research site offered a robust version of what could be possible in terms of being well established and still fast evolving with its range of facilities, technologies and teaching provided through partnerships with different disciplines (see case study research site information below 1.3). As such a single site exploratory ('to *explore* a phenomenon about which not much is known' (Ashley, 2013, p.102) and to an extent evaluative, case study of this emerging academic library makerspace made sense as an approach. Thus, my case study can be considered 'key' in terms of subject type (Thomas, 2013, p.152) in relation to a US view on academic library makerspace. Still, given the lack of current evolution of this phenomenon in the UK, it could also be considered to be an outlier exploring more ambitious cross-disciplinary plans than can currently be found in UK HEIs and many other countries.

A case study, although narrower in focus than many other approaches (e.g., a multi-site quantitative-based approach) allows for more in-depth research to be carried out into the complex, unpredictable creative agency and actions of specific local communities of interest. That is in keeping with the realism of my paradigm. As shown in my literature chapter there are significant gaps in research knowledge regarding academic library makerspaces, and an in-depth look at a well-established one such as that found in this case study could be practically informative for a contemporary audience, as well as prompting further areas of research. As the educational philosopher Richard Pring (2004) observes, there is often a false dichotomy between in-depth qualitative research and large-scale quantitative studies: the ‘qualitative investigation can clear the ground for the quantitative – and the quantitative be suggestive of differences to be explored in more interpretive mode’ (p.243). Within this emerging area of research, a more in-depth interpretive approach enables one to explore further the nature of this phenomenon before meaningful cross-site studies can be established. Thus, the methodology for this research can be defined as a ‘single-case design’, meeting three of the four types of criteria identified by Yin (2009, p.44). It can be considered a *representative case* of the emerging phenomena of academic library makerspaces in higher education. It can also be considered both a *critical case* in how it challenges ‘traditional’ library services and academic teaching, and a *revelatory case* of what is possible for an academic library makerspace service, in terms of the broad range of cross-disciplinary learning opportunities offered (all terms above in italics, Yin, 2009).

With a broad range of established services, this service can act as a prototype of what is possible from an academic library makerspace. As Yin (2009) observes, a case study is a suitable methodology for looking at ‘how’ questions, and this enabled me to track in detail *how* this makerspace service evolved, *how* emerging and sometimes ongoing tensions and challenges have been addressed, and *how* the social and embodied nature of maker-learning is scaffolded through relational work and support across disciplinary boundaries by library staff. The case study approach with its need to achieve validity through the gathering of data (interviews, observation, documents) that is ‘socially situated, and socially and culturally saturated’ (Cohen, Manion & Morrison, 2011, p.180) also fits well with my in-depth cultural-historical framework.

5.4 Ethics and risk management

Ethical clearance was sought and approved before the data collection process. As Mears (2012)observes, at the core of the ethical guidelines is the imperative to ‘first, do no harm’ (Mears, p.174). For this research I have adhered to the British Education Research Association (BERA): Ethical Guidelines for Educational Research (BERA, 2018), and Oxford Brookes Research Ethics for Research Involving Human Participants, a Code of Practice. A full list of risks identified, and examples of actions taken during the research process are given in thetable in Appendix 8. The research was carried out with 14 participants from the case study university, all over 18. The research was relatively low risk as I was talking to fellow professionals, academics and adult students. However, I was still cautious about all potential risks, including appropriate consent forms, member checking and the opportunity for participants to withdraw at any point. I member checked all participants by sharing the transcript of the interviews for accuracy, and anything participants might want to add or remove from what they shared (none did). Interviews with academics and professional staff were straightforward in the sense that all participants were used to both interviewing and being interviewed. I received positive responses from all participants through the member checking process and encouragement for the rest of the research process.

With regards to the online research (the email and Google meet interviews with the makerspace project manager), I consulted recent literature on best practice. Essential advice taken on board included the importance of data security (Gibson, 2017). As the research participant and I both worked for institutions using Google as an enterprise platform, I was able to confirm with IT data from the email interview and the synchronous Google meet interview could be kept securely as text and video respectively. Data Security was also observed with data collected through the face-to-face interviews with recordings held securely on Brookes' Google enterprise platform, and all text from transcriptions and activity observation notes also held on password-protected Google docs.

Beyond wishing to do no harm, my ethical concerns also extended to wanting to benefit participants through seeking a broad range of the maker user voices, hopefully empowering those whose voices may be less heard. Seeking inclusivity, I made sure during direct observation of activities to talk to what appeared to be less confident or non-typical makerspace users, so that their opinions could be included and valued. As the subsequent chapters show, some of my richest data came from Latino students with backgrounds where maker culture was out of reach, as an unaffordable middle-class phenomenon. I also took care with the staff who worked in the makerspace who I interacted with the most not to interrupt their workflow, or to press them for information beyond what they were comfortable sharing. Any insights gained through this research were entirely reliant on the patience of research participants, and their thoughtful responses to my questions, providing rich data. I was also moved by one of the student workers in my final days at the research site, who gave me a maker key/tag before I left, as a symbol of our mutual involvement and interest in maker culture.

5.4 Case study site

5.5.1 Population of interest/ Research sample

This case study took place at a North American university's academic library service that hosts two makerspaces: a smaller one (Campus 1) which is now a 3D printing service and a larger one (Campus 2) with a variety of technologies and services as outlined inthe introduction. For my research sample, I intentionally selected a variety of stakeholders that would reflect different users and types of support staff. The sample includes individuals with disciplinary and professional outlooks, student learners, and a range of library and student workers supporting the space.

There was a total of 14 participants. Introductions to all of them can be found below (pseudonyms are used), showing how they have been purposefully chosen for engagement with library maker services from different perspectives representative of the main users of the space: For example, in 2019 (see Appendix 6) the three top user types recorded in the main library makerspace were: Engineering- 6752, Science- 1535, Humanities and Social Science- 557. Participants held a range of views on the makerspace service, both critical and supportive.

5.5.2 Participant Codes

These labels are designed to help with orientation regarding cultural perspectives with data engaged with in the following chapters. Full pen portraits of all participants can be found in Appendix 1. These portraits helped me to analyse research participants' own sociocultural perspectives in relation to the emerging makerspace service.

PRO = Professional and Paraprofessional Staff (x5)

LIB = Qualified Librarian (x3, also included in PRO figure)

AC = Academic (x5)

STU = Student (x6, x2 also included in PRO figure)

HUM = Humanities

STEM = Science, Technology, Engineering, Mathematics

STEAM = As above where A = Art

5.5.3 Participants

Below are brief profiles to introduce participants' backgrounds and viewpoints:

PRO/LIB/1 (Adrian) - Head of Making and Innovation Studio (male)

Adrian is a professionally trained librarian who directs and manages the university Makerspace program which is situated in the libraries with a full-time staff of 2.5 FTE and 9 student workers. Adrian described the nature of his role and how he got involved in it: 'My role is to direct this program in such a way that it has a meaningful impact on student success across the disciplines. I was a part of launching our makerspace program in 2012-13 with our first space in the newly-opened Library. I... originally got involved in this work because I was excited about the nascent so-called "maker movement" and the growing accessibility of affordable digital manufacturing and physical computing tools. I had some experience with these as a hobbyist but saw great potential for them on the university campus and for the library's community-building' (Adrian/ PRO/LIB/1).

PRO/LIB/2 (Chris) - Experiential Learning Librarian (male)

This role was recently created, Chris started it in July 2019. Before this role, he was a Libraries Fellow undertaking a fellowship incorporating supporting teaching and learning in the makerspace for two years. Whilst at library school Chris worked in a science library makerspace. Although interested in the learning affordances the makerspace service offers, Chris is wary of being typecast in a purely maker-focused role, as it may become something all information professionals may need to be aware of in future (as with roles such as Audio-Visual Librarian that no longer exist).

PRO/LIB/3 (Daniel) - Head of Department: Learning Spaces and Services (male)

Daniel described the evolution of the makerspace service at the case study university as starting from a personal interest in maker activities held by both Daniel and Adrian, and some awareness from people in the library IT section: 'Adrian and I both shared an interest in these kinds of tools, we were responsible for the tech lending programme at the university. So the maker movement, maker education, this is 2010, 2011… Arduino and those kinds of things were on our radar, and it was first initiated, probably, through our tech-lending programme' (Daniel/ PRO/LIB/3).

PRO/STU/HUM (Mariana) - Graduate Extension/ Teaching Assistant/ PhD student in Communication, Rhetoric and Digital Media (female)

As well as working as the Graduate Extension Assistant for the makerspace, Mariana works sometimes as a Graduate Teaching Assistant, particularly for the English department. Mariana is also a second-year PhD student in Communication, Rhetoric and Digital Media (CRDM). Mariana was hired in the spring of 2019 as an hourly worker before taking on the Graduate Extension Assistant role fully. Mariana has an interest in maker-learning in terms of 'transfer' with more rhetoric-based forms of learning.

AC/HUM/1 (Hazel) - Associate Professor of English, Language Writing, Rhetoric/, Digital-Media (female)

Hazel is an Associate Professor of English with a background in electronic literature and Digital Humanities. Hazel teaches as part of the language writing and rhetoric division of the English department, mostly upper-division undergraduate writing classes (in style and discourse analysis). Hazel also teaches in the PhD programme for rhetoric and digital media. Hazel and her students have engaged with the library makerspace to an extent but through a critical/ 'Digital Humanities' lens.

AC/HUM/2 (Maddie) - Associate Professor of English: Women writers 16/17th century English Literature, History of illustrated texts, Contemporary graphic novel. (female)

Maddie's primary research area is 16th and 17th century English Literature, in particular women writers and book history ('the material conditions of production, details of books themselves... other textual forms, scrolls roles, posies... all those kinds of elements of textual material culture', Maddie/ AC/HUM/2). Maddie's secondary research area is the contemporary graphic novel and the history of illustrated texts. Maddie teaches the first half of the British literature survey (Beowulf to Milton), the graphic novel, as well as a specialised course on women in comics.

AC/HUM/3 (Peter) - Associate Professor of English (Digital Humanities- male)

Peter, who trained in 19th century British literature, was hired in the English department to focus on Digital Humanities. Peter's interest in Digital Humanities started at graduate school and has been pursued on and off in his career, his primary focus in his role of 'developing courses and being a liaison around the region helping to coordinate faculty efforts' in terms of outreach and partnership work (Peter/ AC/HUM/3). Digital Humanities courses include an

‘Introduction to Digital Humanities’ that Peter teaches on. Digital Humanities is described by Peter as being more distributed at the case study university than in many others in the US:

> [The case study university] is like a STEM school plus agriculture plus veterinary medicine. The Chancellor once said it was a STEAM school, and I got very excited about that until he clarified that the A stands for Agriculture! So the humanities are not necessarily a strategic priority. (Peter/ AC/HUM/3)

AC/STEM/1 (Charlotte) - Teaching Assistant Professor Biological Sciences, Genetics, Cell Biology and Immunology (female)

Charlotte is a Teaching Assistant Professor in the department of biological sciences with most of her time spent teaching in the ‘elementary genetics lab’ (a lab for genetic experiments and demonstrations using a variety of bacterial, plant and animal organisms), along with an upper-level molecular genetics lecture course. Although she teaches genetics, her research background is mostly in cell biology and immunology.

AC/STEM/2 (Miranda) - Teaching Assistant Professor Biological Sciences, Genetics, Cell Biology and Immunology (female)

Miranda is also a Teaching Assistant Professor in the department of biological sciences teaching on the microbiology undergraduate program. The program has a variety of courses including general microbiology, medical microbiology and immunology. Teaching includes face-to-face active learning classes and online formats. As a non-tenure track, both the above academics don’t carry out their own scientific research but do work with undergraduate researchers within the teaching lab who do independent research. Charlotte and Miranda also do research around their pedagogy and have developed innovative new teaching approaches around maker activities, which will be discussed in the following chapters.

STU/PRO/STEM (Nathan) - Technology, Design and Engineering Student and Makerspace Helper (male)

Nathan is studying technology, design and engineering and is also a knowledgeable library makerspace helper. Nathan has a long-standing interest in making and is an enthusiastic user of the makerspace when not working in it. He has led on innovative maker projects as I shall show and has an infectious enthusiasm for making.

STU/STEM (Edward) – Engineering Student (male)

Edward is studying bioengineering with a concentration on bioprocessing engineering. Whilst considering makers ‘cool’, Edward is more focused on becoming a professional engineer with higher levels of skill.

STU/STEAM/1 (Rachel) - Graphic Communications Student (female)

Rachel is studying Graphics Communications, which includes STEM-related skills such as digital design, Autocad, and advanced SolidWorks. Rachel’s interest in making extends to using the library makerspace for personal use.

STU/STEAM/2 (Jack) - Graphic Communications Student (male)

As well as studying Graphics Communications, Jack has a strong interest in entrepreneurship and a senior position in an entrepreneurial student interest group at the university. Alongside his studies, he is developing prototypes for business ideas. Jack is critical of the library makerspace for the lack of training promoted on more practical use of the tools, such as to repair or create useful objects.

STU/STEAM/3 (Ivy) - Textile Design Student (female)

Ivy is studying textile design, the main topics being concerned with the formation of fabric, and the technology that is used to create and design with fabric. With her highly creative use of maker tools but lack of communication with fellow makers, Ivy considers herself to be an ‘invisible’ participant in maker culture.

5.6 Methods

As Yin (2009) outlines, construct validity is achieved in case studies through multiple research methods and perspectives on the same phenomena, where the same facts are observed from different participant views and using a variety of methods and sources as appropriate. For my case study, I employ a number of Yin’s recommended research instruments, namely semi-structured interviews, direct observation, document analysis and physical artefacts in the sense of objects created in or with help from the library makerspace service (whether directly observed by the researcher or through participant description). The research was undertaken between May 2019 and February 2020. The focus and balance of the research was enhanced by the triangulation of views from professional support staff, academics and students on the critical research questions:

5.6.1 Core Question

How can an academic library makerspace develop as an inclusive cross-disciplinary learning space and service within a higher education institution?

5.6.2 Sub questions

- How did the library makerspace service evolve beyond initial challenges and tensions to aim to support expansive, inclusive, embodied cross-disciplinary learning?
- How are any apparent contradictions between the learning objectives of different user groups addressed in the library makerspace service?
- Is the lack of diversity in STEM challenged by this library makerspace service?
- What are the main tensions and contradictions that need to be addressed to further scaffold critical maker-learning in the library makerspace service?

5.6.3 Research instruments and data collection

5.6.3.1 Document evaluation

The analysis of relevant documents fulfils a critical element of case study methodology by enabling as comprehensive an understanding as possible of the specificity of the case in its context. For my study, this consisted of close reading and CHAT-based interpretive analysis of historical documents relating to how the makerspace project was carried out, including the project proposal and equipment purchased, and the quantitative and qualitative internal research recorded at the makerspace service since its inception. This data allowed me to gain essential contextual information on how the project had expanded and overcome obstacles (or not). The core purpose for this was to provide some contextual information for my cultural-historical analysis of the challenges met in the specific environment, using the archaeology of available knowledge to see how the library makerspace service has evolved. Examples of notes from critical documents can be found in Appendix 6.

A week-long asynchronous in-depth interview was carried out online (by email) ahead of the site visit with the makerspace project manager. Having carried out my initial makerspace research entirely online through emails (Curry, 2017), I felt confident in undertaking this method, which has clear advantages and disadvantages. As Burns notes (2010), there are disadvantages to asynchronous online interviews, particularly an inability to react to body language and voice tone. Jones (2016) also notes some apparent disadvantages (e.g., the lack of opportunity to immediately probe on a subject raised), that can also from another perspective be seen as an advantage (the researcher not being limited to probes that come directly to mind). Burns also notes (2010) some advantages to asynchronous interviews, including being able to follow up on important information and fill gaps on what has been presented. This advantage is also noted by Braun, Clarke and Gray (2017): ‘the researcher and the participant can often think of issues they wished they had raised’ (p.220). I found to get beyond what Burns (2010) describes as the clipped conversation you often get in email discourse, towards more in-depth reflective data, prompting does seem to be necessary. It could also be challenging when trying to avoid interrupting participants’ work unduly. The main advantage of this interview ahead of the site visit was to start creating an initial ‘template analysis’ (described below), a key research instrument. This interview helped me to understand the potential for the library service to support makerspace learning with specific stakeholders (students and academics from a range of disciplines), and across the boundaries between these different groups. All my other interviews were on-site, semi-structured and face-to-face, apart from my last one with the makerspace project manager, which was again online. It is worth noting that I did feel I got somewhat richer and more insightful data from the in-person face-to-face interviews, where I could read people’s non-verbal communication and develop more of a rapport.

A sequence of in-depth (one hour fifteen minutes on average) semi-structured face-to-face interviews were undertaken with the above purposeful sample of participants during a one-week visit to the university in October 2019, including a face-to-face interview with the project manager (further details below). The core purpose of this detailed approach was to provide reasoned in-depth personal views from participants in the groups with their different perspectives, allowing for a nuanced inter-subjective interpretive analysis. Further questions were added for each participant from the initial data analysis when member checking data accuracy by email. The final interview after the visit was again online with the makerspace project manager, this time synchronous as requested by the research participant.

Schedules of interview questions for all participant types can be found in Appendix 2.

[illegible]

Observation of makerspace activities was also undertaken (as agreed with participants; see the section below on research ethics), including a 'making space' event and two class-based activities. This provided an opportunity to look at the reality of the makerspace from another angle, as observational evidence can uncover aspects of a phenomenon that recollections through interviews or surveys may miss. I know from the UX (user experience) approach to library service research that what students think they are doing with our resources is not always the same as their embodied/intuitive actions when observed. Observation is not an easy technique, as well as requiring the cooperation of research subjects there is 'a lot of pressure on the researcher to be alert and responsive to what is seen and heard' (Pickard, 2007, p.208). This method enabled me to see different perspectives on students in the makerspace interacting with peers and meeting their information needs in often spontaneous ways. A schedule was drawn up for this research method, and the field notes template and key notes from my observation of the 'Build Day' in the makerspace (22/10/19) can be found at the end of Appendix 2, (which collates examples of all research methods). The key technique from the literature I found useful for this method of data collection, as advised by Lofland (1971), was to record field notes as quickly as possible after the observation (typing up written notes in my case); this assures relevant information from the observation is prompted by often brief notes before the detail is forgotten.

5.6.4 Data collection activities and schedule

Below is a table outlining the key modes of data collection as outlined above, and how I operationalised them in the research process to focus on the evolution of the makerspace service. Methods used were aimed to focus on different perspectives on how best to scaffold maker-learning, including observing how learning affordances for technologies are supported through meeting fast-developing student information needs. Document analysis was key to complete the CHAT focus on the practical evolution of the makerspaces, and how difficulties were addressed. I analysed this data, as with all the data from this case study (including semi-structured interviews and observation notes), using Sense Making (Dervin & Foreman-Wernet, 2003) to analyse information retrieval from an information professional's perspective and thematic Template Analysis (Brooks, 2015; King, 2016) for broader cultural-historical themes emerging (I explain my use of both these data analysis methods following the table). For the full chronological record of all data collected, please see Appendix 3.

Table of data activities

Data collection activity	**Research focus addressed by the activity**	**Date/s**	**Participants (and how many)**	**How data was recorded**	**Type of data yielded**	**Method of data analysis**
Document analysis	Key makerspace service information/ quantitative data collected from library service (see Appendix 4)	21/10/19	n/a	n/a	Internal reports for case-study university library	Template Analysis
Initial online interview	Building initial template from data from the makerspace project manager for areas to explore in more depth on visit	20/5/19-24/5/19	PRO: n = 1	Online email questions and answers	Text, analysed into codes and themes	Template Analysis
Semi-structured face to face interviews with: • Professional staff (PRO) • Academic staff (AC) • Students (STU)	Library makerspace service from different perspectives	21/10/19-25/10/19	PRO: n = 4 AC: n = 5 STU: n = 6	Recorded and transcribed	Text, analysed into codes and themes	Sense Making and Template Analysis
Observations (x2)	Exploring the learning affordances of maker tools for class-based activities	21/10/19-23/10/19	STU: n=38	Field notes, and questions	Text, analysed into codes and themes	Sense Making and Template Analysis
Email follow-up to interviews (post-member checking)	Checking data accuracy	28/10/19-12/03/20	PRO: n = 4 AC: n = 5 STU: n = 6	Collation of email text	Text, analysed into codes and themes	Sense Making and Template Analysis
Final synchronous online interview	Further questions on key themes established	05/03/20	PRO: n = 1	Online recording	Text, analysed into codes and themes	Template Analysis

5.6.5 Data analysis

I now go to describe my two chosen methods of data analysis and how they link to the theoretical framework and methodology.

For the parts of my data analysis that are concerned with addressing information literacy and students' general information needs in the makerspace context, I drew on Professor of Communication and Library and Information Science Brenda Dervin's *Sense-Making Methodology* (2003). Sense-making highlights the importance of an intersubjective dialogue between the researcher and research participant and has been widely engaged with by researchers in LIS as well as Cultural Studies. Dervin emphasises the dialogic and dynamic nature of communication, critiquing the 'transmission model' where information is thought to be unproblematically put into the heads of receivers. Dervin's model conceptualises information communicated as messages that are tied to specific times, places and the 'perspectives of their creators' as well as 'the extent that they can be understood with the context of receivers' minds' (Dervin & Foreman-Wernet, 2003, p.5). This interpretive approach fits well with my sociocultural/cultural-historical framework, which highlights the importance of understanding in a particular cultural context. Rather than accepting a postmodern stance leading to a relativistic view that there is 'no-truth-only-interests', or a reductive realism that imagines information as absolute objective truth free from any particular observer, Dervin (p. 96) argues that multiple perspectives on the same research object can provide a better view**:** **'**This circling process… provides the means for us to arrive at a more comprehensive, more fully informed, potentially useful set of understandings of the situation' (p.7).

Thus, Sense-Making's dialogic approach fits well with my CHAT framework and helps to underpin my research when explicitly focusing on library users' information needs in an open manner to understand the user's perspective: 'Sense-Making invites articulation by informants on their own terms and not on terms set top-down by systems or researchers representing systems' (Souto, Dervin & Savolainen 2012, p.287). For example, during the research interview with textiles student Ivy (STU/STEAM/3) I asked the following series of subtle open questions to see where gaps in information needs had been filled, without submitting to a purely library service perspective on the services and resources we provide: Did you go into the space with an idea of what you were going to do? At what points in the process are you looking for the online information you mentioned? Where did you get your conceptual information from? What was the end result of the project? Did you get stuck at any point in the process in terms of needing information? How was this resolved?

Whilst drawing on aspects of this sense-making approach to my data analysis, I also engaged with the angle of sense-making described by Dervin as employing a 'utopian imagination' to imagine more ideal scenarios of library service provision as a useful exercise. The dialogical subtlety of sense-making was also relevant. Its connection to my CHAT framework with its focus of multiple viewpoints and potential tensions, also provided opportunities to see when tensions may not always need a collective resolution as CHAT proposes, so as not to relegate all 'divergence to error' (Dervin & Foreman-Wernet, p.146) and to allow room for individual human creativity. My focus on sense-making with regards to meeting the information needs for academic library makerspace was thus beneficial for the in-depth interviews with students I carried out as part of my research. As Dervin and Foreman-Wernet advise (p. 279), 'in studies of *information needs*, emphasis has been placed on understanding how the individual saw self as stopped… and what barriers he or she saw standing in the way to arriving at answers.'

[illegible]

My approach to analysing the text generated by my research instruments that was not explicitly focused on information retrieval behaviours draws on Template Analysis (Brooks, 2015; King, 2016) to focus on broader cultural-historical themes. This approach is built on establishing themes and sub-themes built through categories drawn from the research object. Template Analysis differs from purely ground-up approaches to analysing data by deliberately drawing in initial preliminary *a priori* coding from the first stages of research (or previous similar research), and so intentionally draws from the expertise and experience of the researcher in an applied and transparent manner. Using this method, I established a template as an *a priori* frame from my initial, very useful, interview with Adrian for coding and emerging themes. This met the need found within Template Analysis to capture 'a good cross-section of the issues and experiences covered in the data as a whole' (Brooks, McCluskey, Turley & King, 2015, p.3). These *a priori* suppositions are used as a lens, but potentially challenged, adjusted or discounted and replaced if found to be not appropriate given the research data obtained. This approach fits with my sociocultural/realist paradigm as it is a type of 'subtle realism':

> Template Analysis can also be used in research adopting a 'subtle realist' approach (e.g., Hammersley 1992), a position which acknowledges that a researcher's perspective is inevitably influenced by his or her inability to truly stand outside one's own position in the social world, but nonetheless retains a belief in phenomena that are independent of the researcher and knowable through the research process.
>
> (Brooks, McCluskey, Turley & King, p.5)

The initial template I drew after the first in-depth interviews can be found at the end of Appendix 5.

5.6.6 Analytical process

I developed a logical, analytical process to review all data emerging from the initial template, developing codes into CHAT-based themes (this can be found in full in Appendix 7). My final template can be found in Appendix 5 to show the evolution of the analytical process during my research. Themes and sub-themes established are discussed in depth in the following chapters including the emergence of a specific maker-culture at the case study site through collaboration with humanities disciplines, and the introduction of critical maker-learning perspectives such as 'Critical Making' and 'Digital Humanities'. The nature of maker-learning emerges in the key themes of social *and* embodied learning. The overarching CHAT analysis showed ongoing emergent tensions between inclusivity and specific disciplinary needs in the challenge of creating a genuinely cross-disciplinary, inclusive and sustainable maker-learning service. As Template Analysis tables show in Appendix 5 the interpretive process from the initial interview with Adrian drew out the initially nested theme of relational and partnership work to be an increasingly crucial factor in the evolution of the makerspace service towards inclusive and cross-disciplinary goals (as I go on to discuss in detail in the following chapters). It became increasingly apparent from the triangulation of perspectives on the research object academics and students, that all participants welcomed the increased horizons of social and embodied learning the makerspace offered through its welcoming of different maker and non-maker identities and disciplinary perspectives. Without the relational work of the key professional staff I identify, this expansion of learning affordances and maker-learning possibilities would not have been possible.

The critical methodological insight in this process for me was to work effectively on data collection, sensitivity to the whole interpretive process is necessary from the start of the research process. Through sensitivity to the parts in relation to the whole of the data as the research process develops insights are drawn from the specific to the holistic and back again, gradually increasing understanding. Through each observational and dialogue-based hermeneutic circle (Gadamer, 1975) the factuality, authenticity and actuality of the research object are further established in terms of its emergent reality and future possibilities to 'determine anew the significance of what is examined' (Gadamer, H-G, 1975, p.294).

5.7 Summary of Chapter 5

This chapter covered the reason for the multiple-methods interpretive methodology as the appropriate approach for this newly emerging phenomenon as an exploratory case study from my paradigm of Socio-Critical Realism. The choice of the US-based research site was justified as the case study university has a far more advanced academic library makerspace service than anything currently found in the UK. Ethical considerations were covered, including *primum non nocere* (do no harm) and looking to benefit participants through an inclusive approach to data collection, including voices not often heard in maker-learning contexts. Methods for data collection and the triangulation of a purposeful selection of participants and research instruments used have been described in full to achieve case study validity. Data collection activities are summarised. The analytical process is explained, including the tools used for observing information retrieval behaviour (Sense Making, Dervin 2003) and for broader CHAT themes (Template Analysis, King 2016). Having clearly outlined the methods used I move on to look in detail at the data that was derived.

Chapter 6 CHAT analysis of findings, Historicity

6.1 Introduction

This chapter will examine my data through the lens of the CHAT Third Generation principles formulated by Engeström (1987) and described in my Theoretical Framework and Methodology chapters to help answer the first key research sub-question for this Case Study:

> How did the library makerspace service evolve beyond initial service challenges and tensions?

The following three sections focus on key themes identified by my Template Analysis (see Chapter 5, Methodology): Makerspace library service development; Critical perspectives on maker-learning; The embodied nature of maker-learning.

Contradictions and tensions are examined particularly around how the library makerspace service has met potential hurdles and turned some into opportunities. The dialectical CHAT analysis for each section develops from a practical focus on service delivery to broader topics and issues concerned with tensions between the developing concept of an academic library makerspace, and the existing ideology of maker culture and the maker movement. Anne Edwards' closely interrelated concepts of relational agency, relational expertise and common knowledge (2012) are also used throughout to help show how it is primarily cross-practice work based on respecting the understanding of other standpoints and carefully mediated goals based on shared values, that has enabled the library research participants to expand this makerspace service and offer new services and potentially new creative learning affordances.

6.2 Makerspace library service development

6.2.1 Origins and intentions

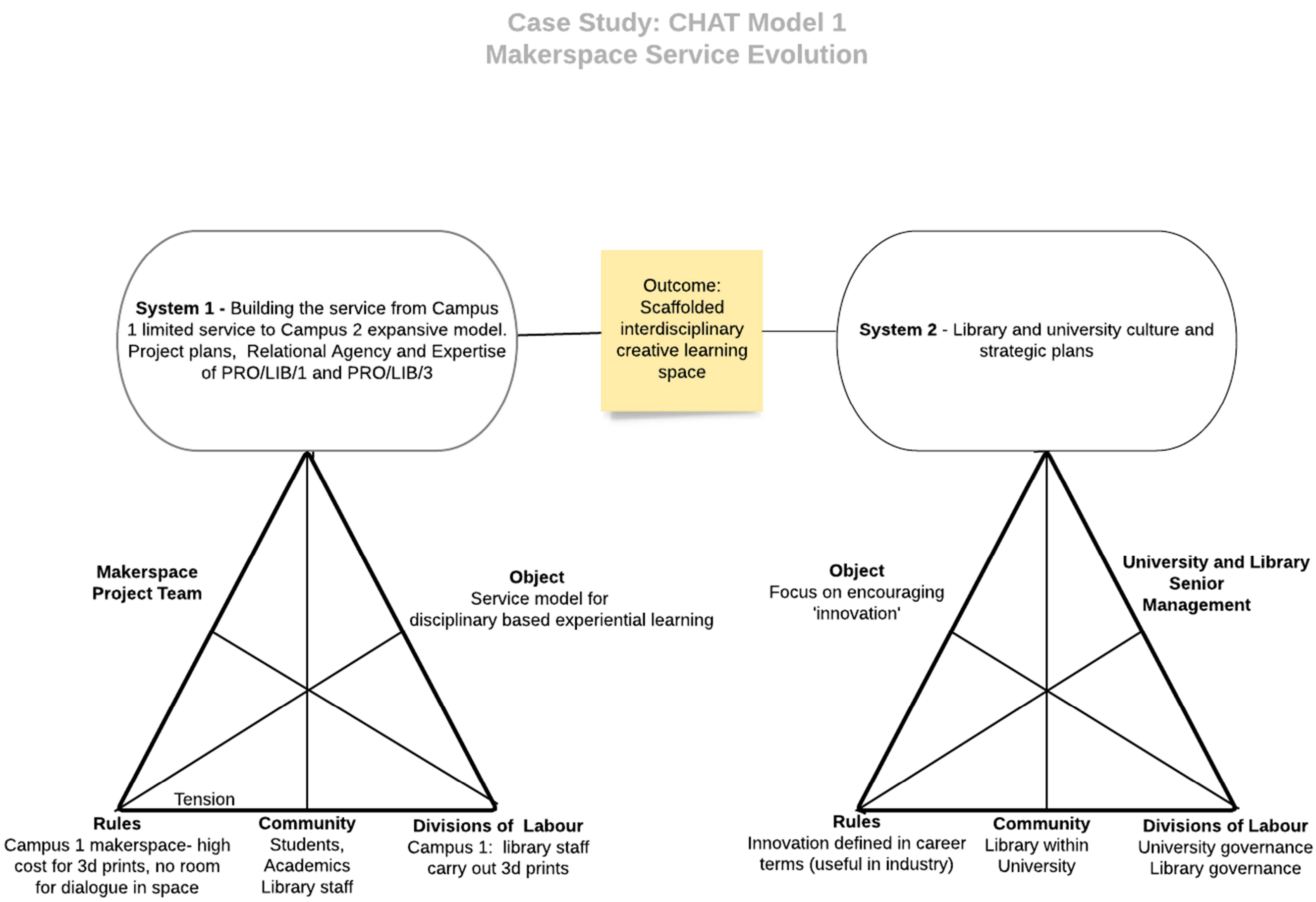
The development of the case study academic library makerspaces was led by Adrian, Head of the Making and Innovation Studio, and Daniel, Head of the Department: Learning Spaces and Services. As described by Daniel, the Makerspace Project team looked at other institutions at a time when there were many more makerspaces in schools, public libraries and museums than in academic libraries. There was HE focus on the project from the start with 3D printers purchased following the model of the University of Nevada. Adrian and Daniel aimed to bring in workshops that are common to many makerspaces, but also class-based activities as found in school and higher educational level makerspaces: 'Not only was it an open lab where people go in and do their projects, we also wanted to make sure the space was adequate for teaching workshops and classes as best as possible' (Daniel/ PRO/LIB/3).

The original library makerspace at the case study university was a small space at the main library on Campus 1 (home of engineering, textiles, some of the science courses, research groups, and local companies) which provided a service based on a limited range of technologies: 'The makerspace was [the] 3D printing and laser cutting closet essentially!' (Daniel/ PRO/LIB/3). The space was supported by student workers, so other students could go in and see the 3D printing happening, but space limitations enforced rules that meant students could not print their own experimental projects. Lending equipment was also part of the service: 'We set up our makerspace as a set of services, so a 3D printing service and a laser cutting service, and then the other things in the lending programme, and then shortly after kind of layered on teaching workshops and started to work with some courses' (Adrian/ PRO/LIB/1).

6.2.2 Initial service tensions

In this section, I discuss the how the initial service tensions around constrictive space formed the problem to be worked on in the makerspace activity system leading to the evolution of the makerspace service, as shown in the CHAT model and the following explanation:

CHAT Model 1: Initial service tensions



A tension quickly emerged with services as students wanted to print their own designs but were not able to enter the space as staff carried out tasks (a tension between rules and learning objectives): ‘It didn't lend itself to trying to print something, failing, changing something, printing it again, so it really wasn't good as an education piece.’ (Daniel/PRO/LIB/3). The initial attempt to recoup finances and create a service that could pay for itself was understandable given the considerable initial outlay (e.g., a UPrint printer that cost $25,000 from the Services' budget). It quickly became apparent that in order to encourage the kind of experiential learning that accepts mistakes and re-prints, aiming for a cost-neutral model was not possible. Daniel also reflected on how the cultural purpose and ethos of a library service contradicts the idea of charging money for services: 'Libraries… we're not good at charging money, ... we're good at buying something and making it freely available to as many people as we can'. The lesson was learnt from the initial makerspace service so that this potential tension was avoided in the new larger makerspace model that was subsequently developed at the library on Campus 2 (home of humanities, social science, agriculture and life sciences) with finance sought from private funding and other means. Data on the success in terms of the number of users, jobs completed, and a new expansive vision was used for the project proposal for the new makerspace in October 2013. This included the 3D printing service printing over 600 models for over 200 individuals (see Appendix 6), and mention of successful projects including:

- Researchers designing a tactile map for blind pedestrians.
- A biology instructor's geometric models of viruses used for teaching their structure (see Appendix 9, Image 10).

The guiding principles for the new makerspace service vision established by Adrian included democratising access for new maker technologies (e.g., 3D printing/ scanning and laser cutting), supporting hands-on project-based and next-generation skills and providing a place for critical and creative thinking across disciplinary boundaries (the outcome in CHAT terms). Adrian and Daniel were able to align the makerspace service project's plans with the broader university's strategic goals for career and economic foci, thus encouraging student innovation whilst justifying makerspace costs.

6.2.3 Service expansion

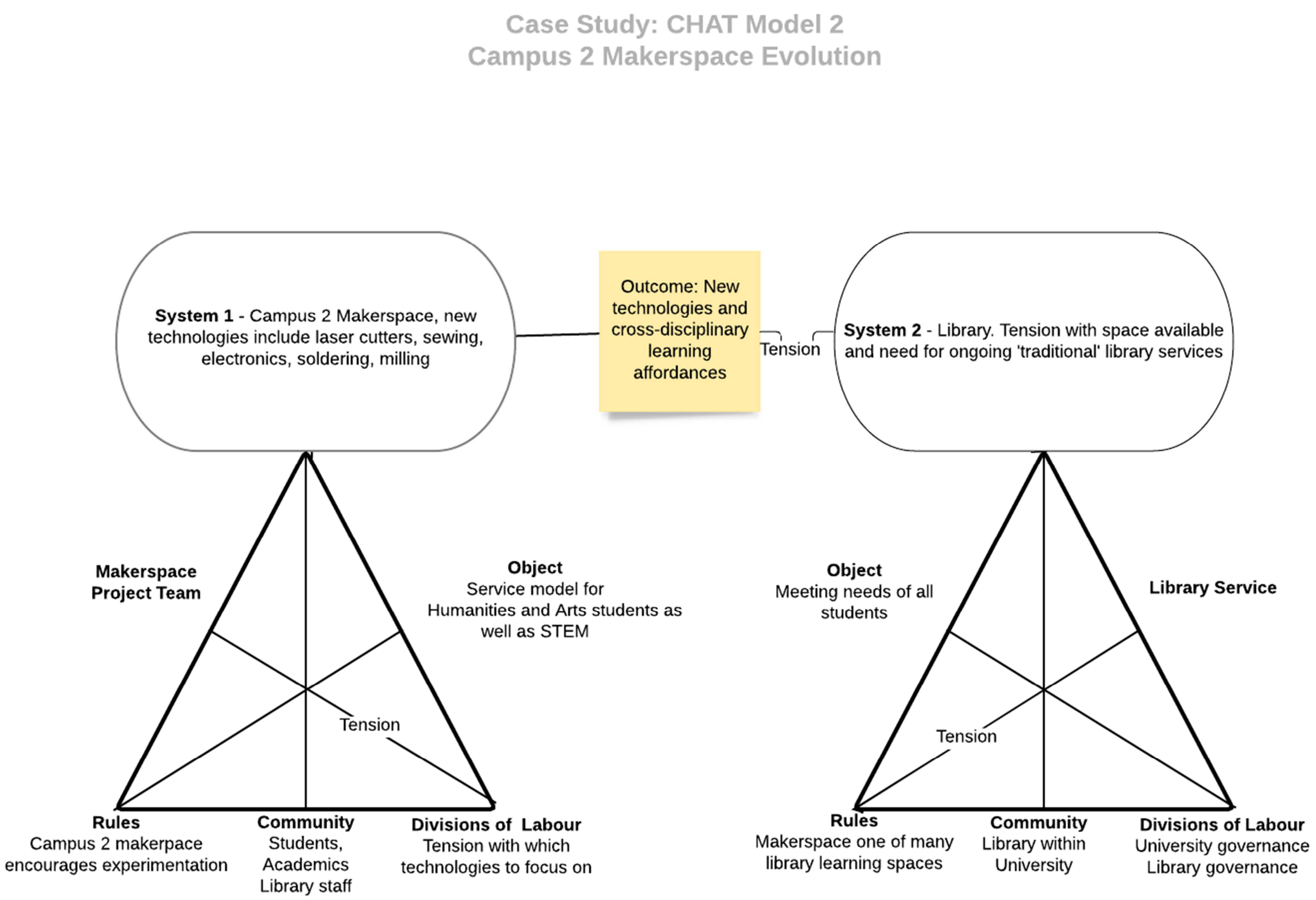
The Campus 2 makerspace service development model was given the go-ahead by library senior management (2014) and established a new kind of service from the start. Adrian and Daniel outlined that from its inception it was to clearly hold 'a broad definition of making and focus on what equipment we think will be useful and impactful for our users across disciplines' (Adrian/PRO/LIB/1). Adrian emphasised how the potential tensions around lack of access, experimentation and high costs for students were all bypassed through the creation of a better equipped, larger, new learning space. Campus 2 offered an opportunity for creating learning services for an interdisciplinary, mainly undergraduate, user base. Adrian described how one of the aims of the new service was to do more teaching to meet the needs of the disciplines in the campus locality (mainly Humanities). The other main aim was to shift 'to a hands-on DIY mode… we wanted to have a space where students could actually get hands-on with the machines and learn them on their own' (Adrian/PRO/LIB/1).

The new makerspace project also bypassed some potential tensions by forming an appropriate staffing model (divisions of labour). Adrian made the point that running a makerspace effectively that includes outreach and instruction is very labour intensive. Initially, they had to make do with what they had in terms of staffing, whilst trying to show senior management what would be possible if and when they could grow their staffing: 'Undergraduate student workers, and later graduate assistants, have been essential to the

Makerspace program; but growing our full-time staff has made it much more impactful' (Adrian/PRO/LIB/1). Daniel and Adrian highlighted how the kind of staff hired was crucial to the accessibility and inclusivity of the space, and to a push for more curriculum integration across multiple course areas (e.g., Engineering, Textiles, Sciences and English). For the makerspace service, lessons were learned from other technology-based services that showed technical knowledge alone was not a sufficient skillset for someone to support learning in the makerspace. As well as good communication skills to teach and train students on the potential value of the new technologies for their particular project, relational skills were needed to make the necessary connections across different academic disciplines so that various disciplinary learning commitments could be understood and interpreted through this new educational tool kit.

Particular challenges emerged around new technologies as the new makerspace service expanded. Adrian, for instance, described how it was an iterative process figuring how to make tools and technologies accessible in the new open space in order to 'help students grow in their learning beyond answering a singular question or need'. Examples of accessibility challenges included 3D printers with their consumable materials, electronics kits with their many parts, and electronic textiles with the complex challenge of needing to know how to sew them into garments for them to have use. Thus, there was some initial tension between tools and divisions of labour as staff prioritised. The development process started simply, evaluating what worked and what did not, getting feedback and 'continuing to prototype new service models' (Adrian/PRO/LIB/1). Adrian also described other challenges that were new to the library service in accommodating a makerspace, including space design, furniture choice, computer security and how to lend very different technologies sensibly. These initial decisions were not just practical, and quickly linked to broader potential tensions around the kind of technologies supported and the allocation of space in relation to disciplinary interests. Choices were made partly to create a more inclusive feel to the space, with much free workspace and a wide variety of technologies (not just STEM but arts and textiles focused) available around the side of the space. Thus, students could create their own environment whilst working in the space and, once tools were put away, the next group of students could create another environment. Possibilities were opened up through this more inclusive space for a more democratic form of maker-learning moving beyond STEM and more commercial interests. This next CHAT model shows the expansion of the makerspace service and tensions around developing technology-based learning affordances connecting more democratically to other university cross-disciplinary academic services and projects, which I go on to discuss further:

CHAT MODEL 2: Campus 2 Makerspace



The new makerspace evolved services using technologies that soon created new tensions, in the sense of being successful enough in their own right to make the new space restrictive. It was apparent early on that the Virtual Reality service needed its own space to meet demand and a new separate service project was scaffolded around the potential learning affordances of this new technology. The makerspace project's initial and ongoing challenges had moved on from the immediately practical to the more complex challenges of 'developing a pedagogical approach and a curriculum as well as a strategy for engaging our community (and importantly, University courses)' (Adrian/PRO/LIB/1). This was and continues to be, an iterative process involving input and feedback from library staff, students and academics. Adrian described how makerspace library staff are involved in the pedagogical co-development of assignments and tailored teaching for maker-related design rather than whole course development. However, this may change with the ambitions of the new Experiential Learning Librarian role (Chris/PRO/LIB/2). Particular university programmes, such as the 'Think' programme, a quality enhancement plan designed to improve critical and creative pedagogy, have been engaged as a partner regarding library makerspace learning opportunities. Chris describes below how the relational agency is often prompted from the academic side:

> The makerspace has a really good partnership with [the person] who oversees the Think program… and they have to do a hands-on learning exercise, and they have to involve critical and creative thinking. And then they'll come and talk to me.

Adrian described how the Office of Faculty Development was also relevant as it was an accreditation body that could be used to reach faculty across the full array of disciplines. Increased awareness of the new library makerspace was also achieved through the yearly library-led Make-a-Thon, a weekend of maker-based innovation to research, design and prototype solutions to sustainability issues held in February. Prototypes are evaluated by judges from the community and local companies with prizes including $2,000 to the winning team.

Although most of the focus in the library makerspace development has been internal, there has been some external outreach activity, such as library staff giving talks at the nearby Science Museum with equipment and information from the makerspace. As early developers of an academic library makerspace, Adrian and Daniel often did events where they talked about 3D printing and why it made sense as part of a library service, challenging perceived tensions around the library space usage such as always prioritising book storage space, to include other kinds of resources and services. This outreach also served a marketing purpose with Adrian and Daniel able to discuss the benefits for students from all disciplines through the case study university makerspace programme. Outreach activities, although becoming less frequent because of the need to focus on the internal development of the space, came to include tools such as VR, 3D scanning, building simple electronic LED circuits, Spiro Art and 'robot balls'. Daniel also did a workshop at a local music festival that involved vacuum forming.

As an early example of an academic makerspace moving beyond being basically a 3D printing service, the case-study service was one of an increasing number of US academic library makerspaces expanding similarly (e.g., Northern Arizona University's 'Makerbot Innovation Centre' mentioned in the literature review) to a much broader remit around cross-disciplinary maker-pedagogy, outreach and social justice concerns. Many of these makerspaces faced similar challenges (e.g., the University of Maryland's problems, mentioned in the literature review, also included space, costs of new technologies, and how the space was to be governed and shared). Where the case study service seems to have progressed more effectively than some is with the wide variety and high turnout for workshops (for a complete list of workshops available when I visited see Appendix 6). For example, from the literature review DeLaMare Science and engineering library at the University of Nevada, Reno-University libraries (Radniecki and Klenke, 2017) struggled with the low turnout for workshops despite high one-to-one support figures. It became apparent during my research that the key factor in the success of the comprehensive programme and high attendance was due to the relational focus of the makerspace project in building bridges across different faculties.

6.3 Relational focus – cultural differences

As well as the relational agency and relational expertise required between the library makerspace staff, academics and senior university management, there was also the need to seek outside-of-university funding. This is a markedly different model to that found in UK HE culture presently, where the senior management of the university and senior academics may be involved in this kind of broader fund-raising liaison work, but academic library staff generally are not. The case study university has a 'Friends of the Library' group consisting of corporate, business and individual members drawn from alumni and beyond. Library staff are involved in liaising at events such as an 'After Dark' evening event where potential donors can experience new library services such as VR, drawing with a remote-controlled robot and 3D printing. The importance of bringing in potential funders through events such as this was highlighted by Adrian:

> A lot of what we are able to do in the makerspace is made possible by donations that came… from that funding.

Although the allocation of funds through private funding could be perceived from a UK perspective as possibly creating tensions as to what this capital is designed to operationalise (e.g., more of a commercial focus?) there were no apparent restrictions or caveats attached in this case. Daniel described how funding was also received from Museum and Library Services (MLS). Adrian was on a project to create best practices with makerspaces from the Chicago Public Library, The Exploratorium, and the Children's Museum in Pittsburgh which received MLS funding. 'The proposal probably got accepted... partly because we were an early academic makerspace, so we were able to be a part of that' (Daniel/PRO/LIB/3).

Certain key relational aspects to the development of the makerspace programme were also apparent when interviewing the current makerspace Graduate Extension Assistant Mariana (reporting to Daniel). She is also a PhD student in Communication, Rhetoric and Digital Media and sometimes also a Teaching Assistant. It was through Hazel (Associate Professor of English, Language Writing, Rhetoric, Digital-Media) that Mariana first experienced the makerspace with course-related maker activities. Then, through their shared disciplinary interests and commitment to exploring the potential learning affordances with connecting the professional writing programme to the library makerspace, both have started co-exploring possibilities around particular technologies, such as digital embroidery and how to get them 'up and going so more people have access' (Mariana/PRO/STU/HUM).

6.4 Critical perspectives on maker-learning

6.4.1 Expansive learning in the ZPD

Much learning in this makerspace could be seen in terms of Lev Vygotsky's concept of the Zone of Proximal Development (ZPD) introduced in the Theoretical Framework and Literature Review chapters, whereby a student can learn through a sense-making dialogue with a more knowledgeable teacher or peer just ahead of their current learning level to solve a problem. The advantages of the new makerspace on Campus 2 included evolving to a space where students could learn from each other, getting beyond the initial tension in the Campus 1 makerspace where students wanted to use the equipment themselves and discuss processes within the space. Thus, the technologies that served as mediating artefacts in the makerspace are now more fully educational learning resources. For example, Ivy described how she learnt from other students who were just ahead of her in terms of maker-learning (thus in the ZPD), in particular with regards 3D printing. This Textiles student learnt from a student studying Biological Systems Modelling who was designing a 3D printed object that could become a mediating tool in science learning activities by acting as a molecular model/formation puzzle. 'It was interesting to see how the 3D printers could be used to make something that people could learn from, rather than a piece that can be used for something that has a function' (Ivy/STU/STEAM/3).

These more sophisticated uses of the 3D printer were deliberately chosen by Adrian and Daniel to display in the area on permanent view through the glass at the entrance to the makerspace on Campus 2, as described in Chapter 1 (examples of objects can be seen in Appendix 9, images 8, 10, and 11). This display acts as a permanent incentive to student and staff to see beyond the apparent contradiction of using technologies that can be just used for fun (e.g., 3D printing of a favourite superhero) for educational purposes:

> It's so useful when you are bringing a faculty member in there… to turn round and point to an item… that may be an English class or a History class rather than an Engineering class. (Daniel/PRO/LIB/3)

As well as a large variety of course-based instruction (e.g., Technology in the Arts, Electrical and Computer Engineering, Multimedia Production and Digital Culture), the library makerspace service also offers workshops on various skills to get students from all disciplines going with their own projects (e.g., Getting started with 3D printing, Arduino, eTextiles, the Internet of Things).

Mariana reported that dialogue with students was common, except when students indicated that they did not want to be disturbed (e.g., wearing headphones). However, users generally considered interruption for conversation to be a good thing in terms of sharing knowledge and creating a community feel for the space. For example, Ivy reported enjoying not just the hands-on experience afforded by the makerspace, but also the input from other students whether expected or not. Often peers in different disciplines could offer insight into what one was working on and sometimes provide more advanced knowledge a bit ahead of one of the student's current learning. They could then carry out similar tasks themselves individually through practice, with eventual psychological internalisation of the new learning gain and knowledge application. The potential value of needing to articulate one's actions whilst in the ZPD suggests how philosopher Robert Brandom's (2000) language- and logic-based concept of 'inferentialism' with its emphasis on the value of articulating reasons is relevant here. As Ivy noted, 'You might not be expecting people to come up to you and ask, 'what are you doing?' And you might not really know how to explain it, but the process of explaining it can sort of bring you to a new idea' (Ivy/STU/STEAM/3).

It can be argued that creative activity is a tacit, largely non-rational process, a view most notably originating in Plato's *Phaedrus* and his claim that the poet finds inspiration in the divine madness of the Muses (Cooper, J.M. & Hutchison, D.S.,1997, p.523). As non-rational process it can be seen as often best not articulated (or interrupted, as by the person from Porlock who famously intruded on Coleridge's writing of *Kubla Khan*). However, it can also be argued creativity is largely a reason-based process (another idea with a long history, for Aristotle poetry was created through a rational process from singular experiences to potentially universal truths (Barnes, 1984, p. 2323)) enhanced through dialogic interaction. I certainly found in my makerspace research 'interruptions' to intuitive embodied activities for the purpose of rational explanation, rather than unnecessary digression, *could* lead to greater understanding and new creative ideas. Through making thought explicit in a dialogue so that a normative understanding is achieved, a person articulating their thoughts can benefit by a fuller realisation of developing ideas through the process of explaining, as Ivy and others in my research found occurred in maker-learning. Thus, this search for normative understandings in the cross-disciplinary learning process apparent within the maker-learning ZPD, spontaneously developed in cooperative dialogues, could lead to potentially new maker activities as Ivy explained. This learning process can be seen in terms of language-based aims and concepts moving across disciplines in a dialogic mode of the inferentialist understanding of logic and language outlined by Brandom (2000), making learning gains explicit as part of an 'implicitly normative, essentially *social* practice' (p.34). Thus, from what I have observed of maker-learning the kind of social interruptions to activity, inherent in makerspaces, can as often be productive as disruptive.

Although there is value in the more spontaneous and serendipitous learning in the ZPD, there is still sometimes potentially higher value in learning from an experienced teacher against some forms of peer-to-peer learning. For example, Mariana described the following teaching process within the makerspace with students: 'I try to establish what students know and go from there, particularly because I try to meet them where they are at, with their knowledge to try and use some of their concepts to explain' (Mariana/PRO/STU/HUM). This ability to meet people 'where they are' by using 'their concepts' to try to develop knowledge is likely to be often better undertaken by someone with experience of teaching and encouraging/supporting students, rather than a random peer who may be less articulate and able to communicate easily with the other student or may not always possess relevant knowledge. This observation of importance of the professional, knowledgeable support, offered to scaffold learning in the makerspace led me to more fully critique the value of maker culture in this HE context.

6.4.2 Variable Perspectives on Maker Culture

It became apparent during the research that the varying perspectives of research participants challenged the notion that enthusiasm for maker culture was necessarily a key component of maker-learning in a university setting. This raised the further question of whether unproblematically presented/overt links to maker-culture could in some ways be a barrier to inclusivity. Across all research participant categories (professional and paraprofessional staff, academics and students), there were very different perspectives on the extent to which this academic library makerspace could be considered part of maker culture.

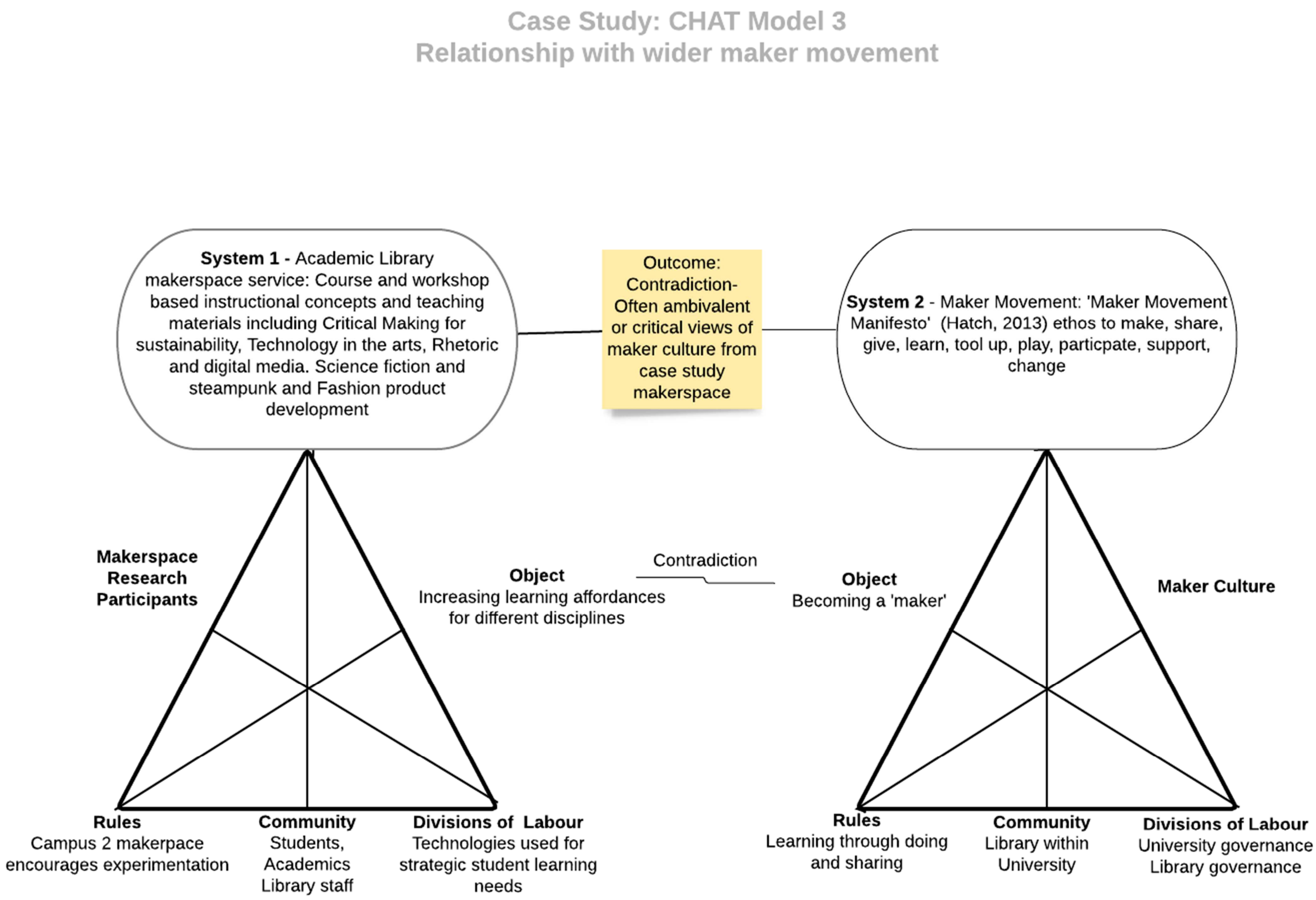
Among the professional staff, Adrian and Daniel were well aware of maker culture and found it an inspiration for starting the makerspace service. Daniel described how the ethos of the maker movement is apparent in the makerspace service to an extent in the way that users help each other and collaboratively share knowledge, describing how students interact to ask about each other's projects. Nathan explained his long personal history of making and tinkering and his growing awareness of maker culture as he grew up with a parent focused on DIY and making, but not aware of ‘maker-culture’. Edward, although aware of maker culture as something enjoyable, saw its DIY approach as somewhat below the level of expertise he was aiming for in becoming an engineer: 'a maker is definitely cool but… I want to do this for a career so let's upgrade it to engineer' (Edward/ STU/STEM). Two of the students were happy to describe themselves in terms of being 'makers'. Rachel, for example, said, 'I enjoy making things... learning about all of the tools, being able to use them safely and well, to go from an idea and draw it, to it's an item you can hold with your hands. So that whole process, it's really cool' (STU/STEAM/1). In contrast to this, from the professional services side of my research, Mariana (the Graduate Extension Assistant/PhD student) had no awareness of the movement from her background. She gave a possible reason for this as the maker movement's lack of prominence in the educational system in New Mexico, where she grew up. Although involved in artistic making activities and aware of technologies such as 3D printing when she was younger, more expensive technologies such as 3D printers were not available for her to work on. The makerspace at the university was initially pointed out to her by a friend. It was interesting the space itself had no overt visual promotion of the wider maker movement other than some books and magazines by the enquiry desk (Appendix 8, Image 9).

A more sceptical view of claims to the ongoing value of the maker movement could be found from Chris. Although enthusiastic about the possibilities of his new role of Experiential Learning Librarian and developing the makerspace as an educational tool that will be ongoing in some form, he considered the specific 'makerspace' branding to likely be of less ongoing worth. Chris described a likely hype cycle with the 'shiny new' makerspace program which might be akin to the older US library concept of computer labs and computer lab librarians, and the current reality. 'There are computer labs everywhere you look, and it's just everyone who needs to be able to troubleshoot problems in [Microsoft] Word… I'm sceptical of the longevity of the Makerspace as a thing' (Chris/ PRO/LIB/2). Although conceding the value of the makerspace brand at present in terms of getting funding and encouraging some students to align themselves with the maker movement, he considered there to be a larger proportion of students that don't consider themselves to be 'makers' and may be put off and think 'I don't know if I can really do any of that'. Chris thus highlighted an apparent tension in that the makerspace branding to further expansion possibilities: 'I think just building the room and calling it a makerspace and opening the door gets us a lot of people, but I want to get a lot of other people too' (PRO/LIB/2). This observation suggests the marketing of makerspaces to students in an HE context may need to be aware from the start of the need to appeal to students with little or no interest in maker-culture.

6.4.3 Digital Humanities and Critical Making

For Hazel, Digital Humanities and Critical Making, while in one sense a part of maker culture, also offer a strong critique of it by producing learning experiences and objects that challenge the STEM-based neoliberal view of 'making' on ethical grounds including sustainability: 'If you want to have a more responsible understanding of making, you have to think about what the making is and does for the human biome, and whether it is necessary to have a space to do that thing' (AC/HUM/1). Although environmental and sustainability issues provide an apparent contradiction in the lasting value of a makerspaces in academia with their potentially high environmental impact, the value of the physical space can be defended on other, more learning-orientated grounds. Below is a CHAT model looking at some of the tensions and contradictions between this academic library service and the wider maker movement which this analysis has drawn out, including specific disciplinary perspectives and strategic student needs that often ignore or contradict the broader ethos of the maker movement as discussed previously (Hatch, 2013). The diagram shows from this case study how a potentially problematic dissonance around the meaning of 'makerspace' in an HE context is apparent in the outcome of the dynamic between the academic library service and the maker movement. This outcome itself suggests a new problem space, whereby the educational aims of the particular academic library service around the more critical/academic focus of the maker-learning available may need to be made explicit. I go on to explore the value of a more *critical* maker-learning in HE in following chapters.

CHAT Model 3: Relationship to wider maker movement



6.5 The embodied nature of maker-learning

Although some tensions and contradictions with the wider maker movement were apparent as in the above diagram (most notably the increasing learning affordances of the makerspace for different disciplines not falling neatly within existing maker-culture and the un-critical call to become a 'maker'), in other ways, this makerspace did fit in within broader maker culture. As with other kinds of makerspace (community-based, public library, museum-based), an academic library makerspace offers opportunities for experiential learning in the sense of learning-by-doing in a friendly environment, involving hands-on social learning activities that can have practical value in the students' wider social experience and life goals. Jack, a student with strong entrepreneurial ambitions, highlighted the makerspaces' learning affordances for hands-on embodied learning and having a more in-depth knowledge of the manufacturing process for technologies we take for granted: ‘If you give an iPhone to a high school student, [and ask them] 'Where do you start on building this?', they would be entirely clueless.’ Jack's example shows how the rational and critical understanding of how an iPhone is built can be enhanced by physically handling similar technologies as part of a simpler version of the 'manufacturing process' that could be undertaken in the makerspace. This embodied sense-making could reinforce and expand on the rational, theoretical meaning that a text describing the manufacturing process would provide. As Gallagher (2012, p. 221) explains,

> The brain doesn't work by itself, … the fact we have hands help to define the space around us in terms of a manipulatory area within which we find and help to constitute meaning . . . Rationality is primarily pragmatic.

The central importance of hand-centred activity to the embodied curiosity and creativity emerging through maker-learning is not something I found to date in the literature. It is perhaps the one unifying element in the enjoyment often found in maker-learning. The spirit of experimentation and learning by embodied/haptic doing in an iterative process that is not hampered by the fear of learning from 'failure', was apparent in all types of users of the library makerspace. This process is a potential tension for some students on less creative technology-focused courses in terms of how they may be used to learning. However, this tension can be seen in an expansive light in terms of challenging learners to learn in a different way, potentially broadening their learning horizons. For example, in the formation of the makerspace workshop programme, Adrian described how workshops were initially tested with academic staff or student workers, often around possible learning affordances with new technologies: 'what do we need to surround that tool with in terms of making it usable and learnable' (PRO/LIB/1). After this development process, only when the prototyping was finished, could the new service be introduced more broadly. This iterative, embodied, learning process was also apparent in Chris's description of the makerspace as a learning tool. Chris described the process of prototyping a new creation as requiring an important kind of critical thinking with materials and tools:

> We teach in a makerspace… We teach you these critical thinking tools. We teach you prototyping… But what we're teaching you are... these creative processes and these... critical processes and these reflective processes that you can apply to any number of different technologies. (PRO/LIB/2)

From an academic perspective, Miranda described the makerspace as 'another laboratory' and space to explore with others: 'both on my own, with our students, definitely. And with… the other staff in the makerspace and even with other faculty' (AC/STEM/2). She described how their (Charlotte and Miranda's) educational research project started in the library makerspace when they looked at creating scientific learning objects (for example, 3D interactive puzzles showing how genes function) using 3D printing through a patient creative process. 'I got to do a workshop at the makerspace, and it was just me in there tinkering for a good semester where I was just kind of trying to learn... what kind of things were possible' (Miranda/ AC/STEM/2). This patient, creative, embodied, critical thinking process was reflected on from a student perspective by Ivy in her experimentation in trying to create a 3D knitted structure. As a Textile Design student, Ivy was very interested in materials and finding out what was possible with them through embodied interaction with and manipulation of the material, 'so it's very much using the knowledge that I have in a way that can be challenged' (STU/STEAM/3). The time she spent waiting for 3D prints was used for testing creative possibilities such as creating holographic tubing pieces that were used in her work. Thus, we can see with this design student a very different kind of 'maker-learning' process to other kinds of student, particularly those with more of a STEAM focus: ‘it is the artisan's desire to see what the material can *do*, by contrast to the scientist's desire to know what it *is’* (Ingold, 2013, p.31).

The design-focused, continually evolving environment of the makerspace offers a micro-sized understanding of how the human mind is restructured continuously to engage with new possibilities in educational settings, through embodied cultural activities in arenas that we iteratively change to our evolving needs. As the philosopher and cognitive scientist Andy Clark observes, the designed environments of structured play in education, art and science become tailored to us and 'they "know" us as well as we know them… As a species, we refine them again and again' (2016, p. 279). Thus, the restructuring of the makerspace itself is a co-productive process between the embodied neurological development of minds culturally engaged with the physical maker-learning space. This co-production includes interests in new technologies becoming tools for embodied engagement in the space according to educational needs explored by academics, interpreted by library staff and iteratively used by students. 'The human-built (material and sociocultural) environment becomes a potent source of new transmissible [mental] structure that trains, triggers, and repeatedly transforms the activity of the prediction-hungry biological brain' (Clark, p.278). Thus, the embodied interaction of people and technologies in a physical space becomes key to the evolution of the particular context dependent maker-learning occurring. The makerspace environment cannot be thought of as static by those who look after the space, as new technologies emerge needing their own physical space and learning scaffolding to meet different disciplinary needs.

6.6 The extent of cross-disciplinary activities

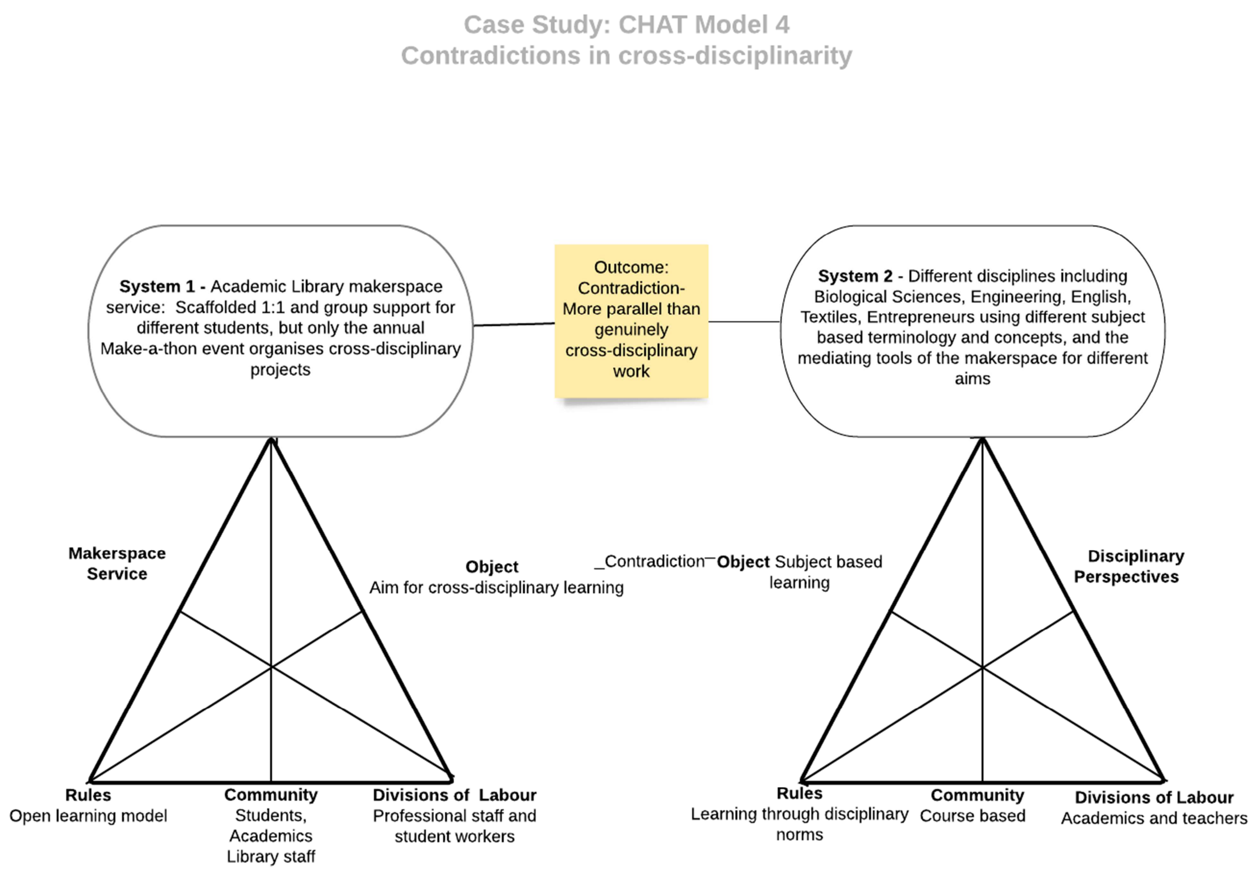
The learning affordances from the cross-disciplinary nature of the library makerspaces were emphasised by all participant types, from students reflecting on the serendipity of finding more knowledgeable others from another discipline who can help with a particular technology (Rachel, Ivy), to professional and academic staff promoting and seeing the advantages of sharing knowledge across disciplines for different perspectives and creative ideas (Adrian, Chris, Daniel, Mariana, Hazel, Maddie). Maddie expanded on the creative opportunity cross-disciplinary dialogue and activities can produce in terms of information sharing to emphasise how this can also help form new knowledge, thus also expanding the possibilities of what an academic library is for:

> I think it creates a kind of point of contact between the humanities and the STEM disciplines. .. To me… the library is becoming like an even more crucial part of the university ecosystem… The library is… almost a lab space for humanists. (AC/HUM/2)

Crucial to fostering the cross-disciplinary nature of the library makerspace was its openness: 'Our library makerspaces are open to all students, faculty, and staff…, whereas many other spaces are only accessible to a particular College, academic department, or research group' (Adrian/ PRO/LIB/1). As well as the access rules of the space incorporating all students and staff, the ethos of the space was to have no academic discipline privileged over another. So, for example, the push from some engineering students to make the library makerspace less about technologies that would be easier for the general user, and more about a high tech/high-quality product focus, has been resisted by the library makerspace service to avoid contradictions in service aims: 'Our goal has been to meet most of the needs of most of the people as opposed to the very specific needs of a very select few' (Adrian/ PRO/LIB/1). Initially, engagement with new technologies to appeal to potential new makerspace users was seen to benefit from staff engagement in an open manner in front of students in order to pique curiosity and prompt questions: 'If there's a particular machine out that they see, either me testing it or someone else, they'll be a little more open' (Mariana/PRO/STU/HUM).

Although I did find cross-disciplinary activity as outlined above, there is a contradiction with any claim this is a fully expansive cross-disciplinary learning space in the sense that most of the cross-disciplinary dialogue between students was through serendipity around the use of particular technologies, or in discussions among those hanging out in the space regularly (which itself shows a learning value of the makerspace). Although the competitive sustainability-focused 'Make-a-thon' event encouraged activity across different student types, this was a once-a-year event. Makerspace workshops would host different types of students who may have interacted in the session and beyond, but there was no clear evidence of this being extensive. Although academics using the space were developing ideas for learning activities outside the norm for their disciplines, sometimes borrowing activities from others, it would seem there is a key current constraint on the further development of this space in terms of ambitions for cross-disciplinary learning that might genuinely challenge disciplinary boundaries to work together on meaningful projects and learning aims. Below is the final CHAT Model (4) for this chapter illustrating the contradictory problem space between the cross-disciplinary aims of this makerspace service and the current reality, something I will go on to discuss in more detail in the following chapters.

CHAT Model 4: Contradictions in cross-disciplinarity



6.7 Summary of Chapter 6

This chapter has looked at the historical process whereby the makerspace service moved beyond initial organisational challenges and tensions. Through the use and analysis of CHAT models built from my research data, the emergence of the Campus 2 makerspace has been shown as a clear move orchestrated by the relational expertise of two key professional staff who saw the potential for wider learning gains from a more extensive, inclusive cross-disciplinary makerspace service. The new makerspace has been shown to have developed through academic engagement across faculties, leading to a learning space where the ZPD emerges in an interesting cross-disciplinary activity space involving unpredictable student interactions and peer to peer learning. However, the contradiction between the cross-disciplinary learning aim and the lack of meaningful opportunities for longer-term cross-faculty projects outside of the yearly 'Make-a-Thon' and day-to-day serendipity between different student types has also been analysed. Critical perspectives on maker culture from professional staff, academics and students have been discussed as well as views from those who consider themselves to be enthusiastic supporters of maker culture. The future of the maker movement within the Academy is therefore problematised to an extent within the apparent contradiction of the connection to the wider maker-movement and the need to include students with little or no awareness (at least initially) of this movement. However, contradicting a simple negative view of the potential for maker-learning in HE, the educational value of the space for new innovative projects outside of STEM has also been identified through Digital Humanities and Critical Making. The embodied nature of much maker-learning is recognised as a key component of my research findings as learners find new possibilities and horizons for technological and cultural understanding through the bodily exploration of the space and intuitive haptic interaction with different tools. This haptic/material exploration can be built on with peer-to-peer conversation and the scaffolded encouragement from professional and paraprofessional staff supporting maker-learning in the space, empowering learners to experiment. The next chapter builds on the insights and inferential understanding of cultural challenges and possibilities built from the historicity of this makerspace service to look at a key central theme found in my data analysis: the challenge of creating an inclusive learning space with the tensions within different disciplinary expectations of 'maker-learning'.

Chapter 7 Maker-Learning Ontology

7.1 Introduction

This chapter builds an ontology of maker-learning from this case study in order to further understand how it can become an expansive educational tool within the Academy. The chapter first looks at the nature of maker-learning across disciplines before introducing the ontology. I then move onto my explanation of the particular kind of constructivist learning I found which offered new opportunities for critical and humanistic learning that engages with material objects in an embodied sense as well as in interesting historical and cultural ways. Lastly, I look at how these new pedagogies combine with STEM concerns around technological awareness and capabilities in a potentially expansive manner for experiential maker-learning within HE.

7.2 Makerspace learning across disciplines

I observed a complex picture of competing, coinciding and sometimes contradictory goals in using the library makerspace (as shown in CHAT model 4 at the end of the last chapter). For example, from an entrepreneurial point of view, as described by textiles student Jack, the library makerspace was useful as an introduction to maker-learning affordances that could be viewed through the lens of small business possibilities. However, Jack felt that ideally, more sophisticated maker services were needed. This was to be found in another university makerspace at this HEI more geared to entrepreneurs and business opportunities that Jack had used: 'The Entrepreneurship Garage'. The Entrepreneurship Garage at the university offers services designed to allay fears about protecting intellectual property rights and has advice on hand geared to supporting the creation of product prototypes. Jack certainly would have liked to see a more entrepreneurial focus in the library makerspace:

> There is a lot of awesome things you can do with a makerspace, and I don't think students understand the full potential of it… you don't have to use it only for class projects, but you can use [the makerspace] to develop an entire business. (STU/STEAM/2)

Jack also had interesting points to make potentially relevant to all makerspace users about the value of the current library makerspace set up. From what he had seen, the library makerspace was good at showing people how to make 'really cool things' but contradicted the full range of maker possibilities being introduced by not putting enough emphasis on *why* you would want to make new things**.** The value of the object/outcome may not always be examined beyond an entertainment or curiosity value. Jack gave examples including the fixing/sustainability affordances of the makerspace such as being at home and finding a piece of furniture needs fixing. For example, a desk is slightly tilted, and a 3D piece printed in the makerspace could fix this. So Jack wished to see 'an emphasis more on **. . .** the applicability of the makerspace and the fact that what you build in there can be used in real life as actual devices, not just little toy things which are built for research and have to get thrown out' (STU/STEM/2). He observed that students used the makerspace to print fun things without thinking much about real-life applications, not just in terms of business opportunities but of making or repairing something that they would otherwise need to buy (thus a perceived tension between makerspace tools and 'rules' in the sense of usual expectations from creative/ artistic (e.g., arts and humanities) and practical/functional focused disciplines (e.g., engineering or entrepreneurship)). Rachel, on the same course as Jack, also had a practical focus on makerspace use and gave an example of when she had repaired a piece of technology rather than just throwing it away and getting a new one. When her iPhone charger was broken, she soldered the wire to fix it so it could carry electricity again.

Tensions between these maker approaches and the learning community of English students also using the space could be seen as Digital Humanities and Critical Making projects have objectives and outcomes from the makerspace that can be conceptual, theoretical, symbolic/ artistic and critical rather than practical, functional or profit-driven. However, what is initially a ‘tension’ when emerging in this new learning environment, can also be seen as an extension to a different kind of learning when accepted as another more critical perspective on maker-learning:

> They [English course-based maker-learning projects] are reflective designs in that they are kind of anti-engineering in that we are not trying to . . . create some sort of efficient answer to a problem, but instead to use the process of making and the materiality of objects as a tool …for bringing out the assumptions, protocols and even cultural conditions of the objects that they evoke. (Peter/AC/HUM/3)

Peter gave examples of Digital Humanities projects, including taking a book and obscuring selected words to create a story or 'evocative' poem in the remaining words. This exercise could be seen to bring out an awareness of narrative and linearity as well as the typographical norms of the page. This exploration of the nature of the book in material culture was taken to another level by a project Peter described that built a 'surveillance book'. A motion-sensing camera was placed to look over the back of *The Adventures of Sherlock Holmes*, and this was connected to a Raspberry Pi microcomputer that was programmed to capture pictures any time it sensed movement in front of the book. The book could be moved around and engaged with by different users: 'It became an extension of a discussion we had about marginalia, about if you think about the book as an object what can you know about its life in the hands of readers or its passage through the world' (AC/HUM/3).

Students tracked the book and used it as an opportunity to think about surveillance, showing it to classmates who found it 'so much weirder and so much more invasive seeming than . . . i-phones that people are walking around with constantly … streaming personal information back to the cloud' (AC/HUM/3). Peter described how he took an 'almost perverse delight' in seeing socio-critical objects such as this, displayed in the makerspace entrance window space, as examples of class activities that contradicted and potentially challenged the more functionally purposeful models of advanced molecules and other more practical projects. Another Digital Humanities object found in the makerspace display was an inscribed 'clay' tablet (Appendix 9, Image 11) made from earth in a student's back yard. This also reinforced how more humanistic projects challenged the idea of maker activities being just about techno-scientific understanding and progress. As Peter described the object: 'here's a clay tablet that one of [my] students made from the clay she dug out her back yard and like fashioned a stylus and wrote a cuneiform . . . as this sort of meditation on inscription.'

This more counter-cultural engagement with the maker phenomenon from the English and Digital Humanities perspective was reflected on by Hazel who viewed the library makerspace as a neo-liberal space inside another neo-liberal space [the university as a whole], mainly concerned with adding to the endowment and aiding recruitment: ‘I really think the glossiness . . . has more to do with public relations’ (AC/HUM/1). However, she did see some positive aspects of this material turn in libraries which involved seeing 'objects as potentially archivable and creatable, manageable in a library context, I think that's really cool, and that's possibly how the librarians themselves think of it as well'. From Hazel's perspective academic librarians may be strategically placing themselves at the forefront of new technology-based educational possibilities, as they see wider possibilities in terms of treating objects and materials as part of the 'learning resources' they organise and promote. Peter also felt it was exciting to watch libraries adapt and become more proactive about their roles in information culture, with the library makerspace being on the edge of what it means to be moving away from print-based materials. Indeed, the case study university's library service has a strong culture of investing in new technologies and being perceived as the library service of the future. The main campus library has such cutting-edge services as high-definition visualisation spaces, digital media creation facilities, gaming spaces and specialised areas forcreating virtual environments.

From a Textiles student's perspective, Ivy highlighted her interest in exploring the possibilities of engagements between particular fabrics and modern technologies through the internet of things, using the 3D printers, the laser cutter, pliers and the sewing machine. Thus, Ivy showed a strong interest in more daring, risky and conceptually driven projects:

> I just wanted to see how the material reacted, like when I held it and ended up weaving through some holographic tubing through that whilst waiting for another print. And that… created an interesting sample that I didn't expect to happen' (STU/STEAM/3).

Again we see potential tensions in meeting so many different student needs with finite space and budget, as this risky, exploratory approach to innovative maker-learning is radically different from many more practical maker pedagogies and projects. These different student needs can also be seen to reflect different views on the world, and different ideological value systems.

7.3 Makerspace Learning Ontology

The contested narratives in makerspace use outlined above require a deeper consideration of the makerspace learning I observed at the level of ontology, in the sense of the reality of being a makerspace learner in this HE context, which I now go on to explore. The table below shows an ontological summary of the learning paradigms of the subject-based systems relevant to this case study, and the activities and learning affordances offered by the library makerspace service. Although the learning paradigms of these subjects are clearly more complex than shown here, this table focuses on the 'radical localism', in Engeström's (1987) terms, of this particular case study. In all cases, the need for the library makerspace service was to:

- Develop tailored workshops
- Develop co-teaching sessions around the most useful technologies
- Provide technical and interpretive guidance on the best use of the technologies to expand learning affordances and complete projects
- Provide easy access to the required learning resources in terms of scaffolded one to one and group support from makerspace staff
- Provide online access to maker companies' information, communities, blogs and free or paid for online training material (e.g., Tinkercad, Thingiverse, SparkFun).

The table below shows how potential tensions/contradictions for this makerspace service are apparent with the different disciplinary perspectives both within and between disciplines. This includes the challenges evident from this case study of avoiding the potential stranglehold of engineering needs on the makerspace service, balancing the educational value of maker-learning against environmental impact, and attempting to ensure maker-learning outcomes have some meaningful 'impact' beyond the Academy.

Table 2: Ontology of makerspace learning

Subject Field	**Learning aims**	**Maker Activity Example**	**Tension/ Contradiction**
Engineering	Efficiency and productivity. Making prototypes to solve problems.	Make-a-Thon: Celebrating successful projects on an ethical/environmental sustainability theme	If the makerspace service expanded, Humanities could lose out to an Engineering focus
Biological Sciences	Increasing understanding of empirical reality through material representations and puzzles	3D printed molecular puzzle: Haptic activities reinforcing reflective learning	Sustainability: These educational tools are potentially disposable and may serve no function beyond the pedagogical
English/Digital Humanities & Critical Making	Cultural exploration, human-orientated values	'Intimate Fields' project remixing historic love 'posies' (a short motto or line of verse inside a ring): Encouraging socio-historical awareness and empowering those with less social and cultural capital	Although aesthetically and intellectually interesting, they may have limited impact and remain as curiosities within the Academy
Textiles Art & Design	Exploring the importance of materials' form and creative possibilities	Pulse Dress using internet-of-things technology: Embodied awareness of material & technical innovative maker tool affordances	The creative possibilities of new technologies are being realised, but taking a step away from 'natural' materials
Business/ Entrepreneurial	Prototypes for products often with a functional or social focus	Syringe filling machine: Makerspace as a supportive experimental design space for Minimal Viable Products (MVPs)	Difficulty in translating innovation such as this into outside wider social impact

The Make-a-Thon, with its environmental sustainability theme, was a commendable activity that illustrates well some of the above tensions/contradictions. While this attracted many engineering as well as other more practically focused students, the difficulty was in attracting those from less overtly technical disciplines with less established creative/technological self-efficacy. There was also an evident tension between the sustainability underpinning the Make-a-thon and the challenge of making a broader real-world impact from projects and outcomes. No significant wider social impact cases have been reported as yet from the Make-a-thon or other makerspace projects from this makerspace service. A sustainability focus was also a challenge apparent to all uses of the makerspace. Although the learning models made for the biological sciences have pedagogical value as haptic activities that can reinforce reflective learning about molecular structures, if they become disposable parts of students' short-term projects rather than ongoing learning tools for other students, they can be critiqued on environmental sustainability grounds. Many of the artefacts created within Digital Humanities and Critical Making projects can also be critiqued on similar grounds. However, this critique must be balanced against the educational value of encouraging socio-critical awareness, thus potentially empowering those with less social and cultural capital. If we look at the potential benefits of socio-critical awareness as something that has potential value as a concept that underpins life-long learning, we might in more subtle ways be able to see 'impact'. This impact would be in the ‘sustainability’ of creative ideas that enhance *eudaimonic* possibilities in the way people live their lives in the Aristotelian sense of expanding the possibilities for human flourishing. Thus, ‘wellbeing’ can be more fully realised with the ability to critically think about changing one’s immediate reality for the better, rather than passively accepting it as can be the case with purely abstract curiosities *or* purely functional maker objects that are not critically aware of sustainability issues or wider cultural concerns.

In spite of the above profound tensions, a consistent picture I found across these many different, makerspace-based, subject-focused learning models, was the value of students working together on projects. Thus, working together showed how distributed cognition could increase the affordances of project objectives and outcomes. Successful maker-learning group work can create a sense of group efficacy (defined as a group's perceived capability to perform (Bandura, 1997)) for innovative projects that could be beneficial for career aims. Through these social-learning interactions, students could start to understand the advantages of collaboration with many minds engaged on the same task, thus expanding possibilities well beyond someone working on a project alone. As Clark explains, 'inter-agent exchanges thus create new paths through the space of possible understandings, allowing websof communicating agents communally to explore intellectual trajectories that would rapidly defeat any individual agent' (Clark, 2015, p. 288). The other consistent ontological factor in maker-learning as previously introduced is its embodied, often haptic, nature. I go on now to explore this now in more depth with examples from my case study.

7.4 Embodied Learning

A makerspace can be considered a social learning environment, in the sense of instructional scaffolding being available and peer-to-peer advice and collaboration occurring from a socially constructed base. However, from this case study it was also clear individuals were inspired by this social learning scaffolding to find their particular creative paths through an embodied, intuitive learning process from moment to moment during activities undertaken in the space. I spoke to many of the students about what they were working on**.** From their responses, it was evident that there were many different types of personally meaningful and exploratory projects. As the following examples show, it was clear that physical/embodied interaction with the technologies and materials as well as memories of previous experiences, cultural artefacts (e.g., films, paintings), and interests, became key to mediating the creative process. One student was in the design phase of a class project on making a personally meaningful object and was working on an idea of showing humans' 'discovery' of violence related to the film *2001: A Space Odyssey*, and the dawn of man scene with apes discovering material objects as 'tools' for violence. Another student's concept was to design a mask to show a happy or sad face, symbolising how we can hide behind fake emotions. When I observed it, the face had been designed using cut-outs from images of a sphere to create a simple design for a smiling face (looking somewhat like Ancient Greek theatre masks), as the student found what was physically possible with the tools and materials available through haptic exploration.

Another example of the breadth of activity in the same class was a student inspired by Pieter Bruegel's painting 'Landscape with the Fall of Icarus' trying to 3D print the wings of Icarus. There was an interesting feeling of deliberative enjoyment in exploring associated with this kind of haptic exploratory learning. Possibilities were emerging from the student's contemplation of initially loosely defined concepts being enacted through embodied movement and interaction with tools in the space, instead of having clearly defined aims from the start that technologies merely served. This slow, playful, materially interactive approach reflects John Dewey's focus on enjoyment as a vital ingredient in an engaged learner. The enjoyable, imaginative and unpredictable nature of maker-learning seems an integral part of its ability to encourage students’ own agency and curiosity as students find they often realise learning beyond what they anticipated. The value of learning by less time-bound, imaginative 'play' is also reflected in recent neuroscientific findings and conclusions:

In the see-saw of attention, Western culture overvalues the central executive mode and undervalues the daydreaming mode. The central executive approach to problem-solving is often diagnostic, analytic, and impatient, whereas the daydreaming approach is playful, intuitive, and relaxed. (Levitin, 2014, p.376)

The most realised concept I came across (which also met the pedagogical aim of encouraging activities that promoted inclusivity through critical thinking) was from a Hispanic student inspired by a song from the musical *Hamilton.* The song by Lin Manuel Miranda 'Immigrants (we get the job done)' describes how immigrants to America from minority backgrounds were/are often exploited for cheap farm labour. The student was 3D-printing a tree, and an apple and table and placing them artfully together to symbolise how the food on the 'high' social table may be picked by immigrants, but they often do not get to eat it.

In conversation after this taught session, Mariana emphasised how the possibilities of maker education encouraged a 'growth' mindset (Dweck, 2006) whereby students believe their capabilities can be developed, improved and expanded, particularly in this case through their maker-learning based awareness of the possibilities of a less logocentric form of communication and creativity. Mariana explained how she considered the physical, iterative process of making as similar to the writing process, but employing a kind of tactile, material-based mode of thought and conceptualising. Researchers such as Engeström and Tuomi-Grohn (2003) have looked at 'transfer rhetoric' observing how learners can increase their existing rhetorical skills within the shared collective activity of different communication genres. Mariana thought the multi-modal learning and communication found in the makerspace might help with students' awareness of varying material-based and inspired communication processes, a necessary skill for jobs in the creative industries. The makerspace activity in the examples described here shows how learning that may seem disorganised and haphazard to the uninitiated can serve to increase creativity and communication skills potentially of use in a diverse range of careers. Thus, Mariana was uncovering the potentially false dichotomy between more humanistic learning and more practical approaches in the sense that both may be providing a wide skill set useful for careers in the creative industries. This productive mixture of the creative and practical can be seen to overcome some of the tensions I have thus described and was apparent in teaching methods I found as I now go on to explain.

7.5 Critical/Constructivist pedagogy

Academic participants acknowledged that teaching and learning in the makerspace could be viewed from a Constructivist perspective, whether overtly theorised in the scaffolding of learning or not. Charlotte and Miranda specifically mentioned a Constructivist-inspired teaching model they used for maker-learning (POGIL, 2020- Process Orientated Guided Inquiry Learning). As described, POGIL is a small team-based learning method in which the teacher acts as a facilitator, with activities designed to be self-managed by the team, with the instructor there to help them construct their own understanding. The learning process is thus scaffolded by the disciplinary knowledge of the facilitator: 'So we do . . . study designs. Then we have the intervention . . . the next class period, for example, where they would be interacting with the models and doing the guided inquiry activity. And then there's always some sort of post-assessment' (Miranda/AC/STEM/2). Charlotte and Miranda emphasised that higher-level thinking is encouraged by applying knowledge learnt through POGIL to new contexts. Charlotte and Miranda described this approach as Constructivist in the sense that the teacher’s expertise is built around the learner’s existing knowledge both prior to the POGIL project and practically build through the creative experiential activity of the project.

7.5.1 Critical Making and Digital Humanities

The academics interviewed who had an interest in Digital Humanities discussed it and Critical Making as two interrelated concepts (e.g., 'I'm interested in digital projects that are self-conscious about their materials, and about the kinds of things that tools can and can't do' (Maddie/AC/HUM/2)). For Hazel, the overlap between Critical Making and Digital Humanities was apparent in emerging student work that combined historical, interpretive and critical perspectives through a maker lens. Hazel gave the example of a project she was publishing which looked at Victorian-era muscle development kits. The kit (which used electric shocks through the body aimed at making the user more muscular) was reproduced to help students think through ideas about Victorian Masculinity, employing a critical, maker-based approach to older technologies rather than written texts. She discussed how there was a tension from some academic colleagues who were more logocentric in their academic approach. Some academics would frown upon some Digital Humanities/Critical Making coursework as producing 'less than pristine objects'. This view was apparent from colleagues who Maddie felt could tolerate any number of poor, often plagiarised, papers produced through 'the traditional sage on the stage, please deliver a paper teaching methods'. Her view of Digital Humanities/Critical Making coursework was that it required students to produce something 'if not original, at least . . . grounded in their own engagement with the material'. Thus, we can see how material-based haptic maker-learning provides a competing pedagogy in the humanities, challenging the monoculture of book-based learning models and showing the diverse range of emerging pedagogies related to maker-learning under the overarching social-constructivist framework.

Another example of maker-learning I found, also suggesting a material turn in the humanities that offers more inclusive maker-learning opportunities beyond STEM, was Hazel and Maddie's work on a project called 'Intimate Fields': 'It's based around the early modern idea of the posy which is a really short little text that people would pass around as... love notes' (Maddie). From her perspective as a literary scholar Maddie is interested in the posy as a genre and how it was embedded in material culture, 'gloves, stitched garments, rings… that kind of thing. I was interested in it as a physical computing project that could take existing posies and remix them and produce new posies' (Hazel/ AC/HUM/1). Early prototyping was done in the library makerspace, although a commercial provider was needed as well as Hazel's own materials, tools and skills. The key technology they found was a near-field chip and reader (a short-range wireless technology that enables secure communication between electronic devices): 'so we had rings that had embedded chips in them we could put existing posies into, and we also had a set up where you could touch the ring to a reader that would generate a remixed new posy and then print it out on a little printer' (Hazel/AC/HUM/1). In this example, we can see an assignment that may have been traditionally imagined as an essay becoming an intriguing and attractive tactile maker-learning object, inviting us to engage with historical expressions of love as dialogic patterns of discourse remixed into new forms. Although in no way negating the academic strength of essay writing, new forms of engagement with the past such as this may capture students' imaginations. This example shows how the potentially 'alien' nature both of historical, formalised and secret expressions of love can become immanently available to use through the equally alien form of a new technology. We can see here an emerging socio-critical, historical kind of maker-learning pedagogy, both challenging and extending traditional Constructivist notions of building on learners' own experience by dialectically engaging with fragments of the lived experience of real people from a previous cultural-historical time. Thus, as with the Victorian Masculinity project this shows how material-based haptic maker-learning can reveal innovative pedagogical approaches for deeper historical understanding for the humanities.

7.6 'Learning resources' as mediating artefacts in maker-learning

The tension I have explored between the creative and the practical was also apparent in library support in terms of resource use and information literacy support in this context. Contradicting traditional notions of what constitutes key library resources, Chris made the point that the hard copy resources in the makerspace (books and some magazines) don't tend to be used for immediate information needs but rather as a kind of source of creative inspiration: 'so I can pull over . . . Make 2019's guide to desktop fabrication and be like, .. this is why we bought this printer, because it's the best one' (PRO/LIB/2). Data from all participants collectively suggests that for this makerspace users' more practical information and resource needs were met primarily by staff and freely available online information whether it be product-based resources, community of interest fora or individual blogs. The most common information-need strategy of the diverse range of Makerspace students I interviewed, when they saw their sense making activities as 'blocked' (Dervin & Foreman-Wernet, 2003) in any way, was to address immediate information needs to a member of staff in the space (whether a librarian or student worker).

Conversations about immediate information and digital literacy needs for using the maker technologies can be seen as part of the base level of learning outlined by student worker Nathan as part of the instructional scaffolding available from makerspace staff. Nathan frequently needed to show users how to use a particular piece of equipment, clearing up any questions or confusions from a diverse range of learner perspectives and needs. I observed makerspace staff watching students follow through on advice so that the member of staff could observe what strategies they used and how much success was achieved, and therefore the extent to which the student was helped by previous answers to his/her needs. Each member of the staff had particular strengths and was aware of when they had the required knowledge to help the student, and if they didn't, which staff member to call, thus showing that the collaborative/dialogic model of learning was also apparent among staff.

Professional staff and academics' descriptions of how students' progress from early makerspace activities in a sometimes guided as well as exploratory social learning process, presents a complex, expanding picture of student learning and information needs in the makerspace. This process is dependent often on the extent of already established skills from particular disciplinary and personal backgrounds. Engineering students predictably tended to be the most immediately adept with maker equipment. Nathan described how over time students either learned to find the information themselves or asked for help more quickly when stopped in their activity. Freely available resources for maker activities, such as 'Thingiverse', an online community for sharing 3D models with over one and a half million models uploaded, were mentioned often by students. However, additional information was often also seen to be needed even when freely accessible resources were available. For example, Edward found he needed support to stabilise some objects downloaded as STL files from Thingiverse, and a student worker in the makerspace told him how to use Meshmixer to achieve this.

However, Hazel made the point beyond practical and technical skills as above the key learning makerspace affordance may be less about technical skills, and more about a significant shift in how some students view technology that may lead to more complex information requirements about building rather than just using technology: 'I think what's useful about makerspaces, is the opportunity to think about technology as being something you make rather than something you use' (AC/HUM/1). I now go on to explore how LIS theory is starting to expand in more academic and critical directions in relation to maker-learning, challenging a purely practical hegemony.

7.6.1 Emerging LIS maker-learning pedagogy

On more practical maker concerns Chris described how more complex information needs were addressed through further dialogue with students by 'consultation requests' with makerspace staff which would last approximately an hour: 'sometimes we fill the entire hour. I say, okay, well here's where we're at . . . make some progress. Here's your next steps.' (PRO/LIB/2). Sometimes students would be referred to information from companies and organisations selling or promoting maker products such as the Raspberry Pi Foundation, Arduino, and Python programming libraries. Chris also emphasised the value of learning resources from companies entering the maker market with a focus on their product as an educational tool, giving several examples including SparkFun who make Arduino kits the library makerspace was using. These kits came complete with wheels, motors, interconnected circuits and if you follow the instructions, 'you've built yourself a line-following robot and programmed it'.

In terms of how Library and Information Science learning theory on information and digital literacy support in relation to maker-learning might move beyond mainly practical support to insights into the nature of knowledge and information, Chris mentioned the potential value of the ACRL (Association of College and Research Libraries) Framework for Information Literacy (2015) for helping to create a shared vision for library makerspace instruction covering key concepts and competencies for a diverse range of learners. ACRL threshold concepts, such as that ‘authority is constructed and contextual’, could be engaged with in maker-learning models. Chris gave a hypothetical example of a learning activity where a particular technology is used to tell someone when their garage door is open, noting that many tutorials are available online to tell how this is done.

> And we could have each person pick a different tutorial and work together to analyse how they're different and how they're the same… you could trace through all those different things just to find out that the fact that they built one doesn't mean that they know how *I* should build one.

In another example of how new critical information literacy perspectives are being supported by academic library-based maker services, Adrian described how ‘Design Thinking’ and ‘Critical Making’ had been adopted as learning concepts taught by makerspace staff in workshops. From what I saw in this case study, and perhaps predictably, Design Thinking was most of interest to STEM users (particularly in engineering and textile design), while Critical Making was more of interest to educators and students in the Humanities. These two key taught concepts could be seen as promoting a diverse view of maker-learning by covering different disciplinary perspectives but had yet to form a cross-disciplinary scaffolding for maker-learning. Design Thinking is a multi-step, creative problem-solving methodology that has been developed since the late 1950s (Arnold, 1959) as a systematic approach to design. The stages of Design Thinking are: (1) Empathise with users; and (2) Define, Ideate, Prototype; then (3) Test the product (Hasso-Plattner-Institut of Design at Stanford, 2020; the library service also used the IDEO Design Thinking Toolkit, 2020). Essentially the process is aimed at improving products by analysing how users interact with them and the conditions in which they operate. More recent academic focus on Design Thinking has seen the conversation move on to ‘value centred’ and ‘worth centred’ design (Cockton, 2006).

‘Whether intended or not, design determines behaviour to some extent and suggests the need for some responsibility or at least understanding of impact’ (Knight, 2008, p.343).

The lens of Design Thinking has thus become more focused on finding the core values of users on which to base the design process as well as the wider social worth of products. Adrian described how it was difficult to do more than scratch the surface of this theory, given time limitations with students. As well as Design Thinking**,** he highlighted how Critical Making was also taught by the library makerspace staff. As previously mentioned, Matt Ratto’s Critical Making approach (from the University of Toronto’s Critical Making Lab) works at the boundary between humanities and engineering, working with 3D printing and digital fabrication often with the aim of ethical, socially progressive awareness and projects (e.g., prosthetic limbs, Ratto, 2014). Critical Making is a Constructionist learning process that involves elements of critical literacy and critical information literacy throughout the process through conceptualising and investigating the critical, social, cultural, political and material issues that surround the making process (thus the quality of final prototypes is not the purpose), resulting in what Ratto describes as an appreciation of ‘nature-culture hybridity’ (2016, p.28). For example, an early critical making student project at the Critical Making Lab saw students building a model of a photocopying machine that used RFID cards to set permissions on the physical copying of books; if the permissions were not followed a message was sent to imaginary authorities, thus asking questions on cultural forms of information control and ownership (Ratto, 2009). Other Critical Makers such as Eric Paulos at Berkeley and the artist, designer and academic Garnet Hertz have also taken conversations about ‘value’ and ‘worth’ in making to areas of global philosophical concern, including the ecological and political implications of making activities.

7.6.2 Critical expansion of 'Digital Literacy'

Hazel was more critical of maker activity than the other participants. When asked whether students' digital literacy is improved by makerspace activities, she made the point that, although specific skill sets may be covered, a 'more expansive' understanding of digital literacy was required that included socio-critical views on the making process. A particular ethical concern for her was understanding the 'material aspect of the digital' (AC/HUM/1), including the carbon footprint of much makerspace technology (she had just finished writing a paper on the high energy cost of making one Raspberry Pi). As well as critical views, Hazel saw positive value in some learning affordances offered by maker culture, while highlighting the fact that 'maker-spaces' have been around for thousands of years 'in the sense of specific spaces where people go to transfer expertise and knowledge about technologies'. She discussed the new sociological learning models emerging with Critical Making and the more recent concept of 'New Materialism' 'where materiality is a term that applies more evenly to humans and non-humans' in a holistic interpretation of social, natural and green materialist aims (Bennett, 2010, p. 111). Hazel saw how objects could be used as another kind of 'text' with metaphorical and symbolic meaning moving from the physical to the digital 'to think about concepts ... the expression of knowledge from one modality to another modality'. Thus, we see again more expansive possibilities for maker-learning beyond the mainly practical which could attract a more diverse student body not just in terms of disciplinary perspective but factors relevant to inclusivity. As different disciplines tend to attract students of different ethnic, gender and social status (e.g., the mainly white, middle class, engineering cohorts found at the case study university against the more ethnic and gender diverse humanities courses) the need to progress the emerging critical and humanistic types of maker-learning (e.g., Critical Making and Digital Humanities) and related LIS scaffolding is apparent.

7.7 Chapter 7 Summary

This chapter has covered an in-depth look at maker-learning across disciplines from my case study, including a picture balancing practical, embodied and critical/creative modes of constructivist learning found. Key challenges for maker-learning in HR are drawn out including the need to make sure maker-learning is not constricted through an engineering-only learning paradigm, such that service tensions are worked through to extend maker-learning to include concepts from Critical Making and Digital Humanities. This tension has clear implications for the library service in terms of how it can reconcile different pedagogic intentions and disciplinary expectations which I introduce and go on to explore in subsequent chapters. Although the library service aims to welcome all kinds of learners and ways of knowing, there are still difficult decisions to be made about where to place the focus in terms of staff, equipment and new projects. Service demands include supporting the high-tech professional engineering world, representative educational tools for biological sciences, the ethical and critical maker concerns of Digital Humanities and Critical Making, and practical and sustainability concerns from the entrepreneurial perspective. Could all these perspectives and concerns be combined in a new, expanded library makerspace model that aims to meet inclusivity and diversity challenges? I go on to discuss this in the next chapter.

Chapter 8 Building library service affordances for inclusivity and diversity

8.1 Introduction

The revealing of tensions between practical concerns and more creative and critical forms of maker-learning from the previous chapter, which link to the possibility of a potentially more diverse maker-learning community, prompts important questions about inclusivity and exclusivity, to which I now turn. The expanding range of ideas, support and possibilities outlined in this chapter from research participants supporting maker-learning, shows how this academic makerspace service has tried to meet the inclusivity challenge. Inclusivity is defined here is the attempt to provide equal access to people who might otherwise be excluded in disciplinary terms, and the associated diversity that attracting different disciplines can bring (e.g., the more diversity in humanities cohorts in terms of gender, ethnicity and background as compared to the mainly white, middle class engineering cohorts). The second and third sections of the chapter further address the related theme of diversity. Diversity is here read as *recognising* and accommodating individual differences (be they ethnic, gender, status or ideologically based). Thus, I look at the extent to which the academic library service can scaffold learning to meet the needs of diverse perspectives. The themes of inclusivity and diversity were relevant to the following key sub-questions for this research:

- How are any apparent contradictions between the objectives of different user groups addressed in the library makerspace service?
- Is the lack of diversity in STEM challenged by this library makerspace service?

8.2 Building inclusivity: the library maker community

The idea of the library makerspace as a learning community or a home for different communities was mentioned by a number of research participants. Daniel emphasised how the sense of community engendered among students using the makerspace could be seen as beneficial to their success as students. The library makerspace provided an easily accessible community and sense of belonging, often to students who may not easily find a 'home' elsewhere: 'I think we've found students that don't have another place that's home. . . They find these spaces and that's where they find a cohort of people that are like them and have a shared interest so there is a social aspect to it' (PRO/LIB/3). Thus, Daniel identified the social aspects and a loose sense of community (rather than a more specific community of practice around particular skills or technologies) as being pivotal in getting students to feel at home and to start learning in the library makerspace.

Mariana also emphasised the general sense of community, particularly for those who find the makerspace early in their student life: 'you will actually see students who come in, they don't really know each other. There's no reason that they should know each other, but they're friends because of that space. Just because that is the nature of it' (PRO/STU/HUM). Mariana also observed students as they become more at home in the space, combining trips to the makerspace with using the library study space. The value of the physical space itself (as opposed to having just a virtual makerspace as an interest group) was apparent to most participants. For example, Peter said, 'I think physical space is kind of crucial as a kind of anchor, this thing exists, and it happens there' (AC/HUM/3). However, Peter also pointed out not all English student cohorts are necessarily interested in 'making' (more recently his cohorts were interested in big data, social and environmental justice), so from his perspective the idea of installing a makerspace on the grounds that 'if you build it they will come' was not sound because prior interest needs to be generated and built on. This observation suggests library services concerned with inclusivity in maker-learning spaces need to be careful about the particular interests of the students who might use the space. The exception to those valuing the physical space was Hazel who questioned the environmental footprint of the makerspace, despite its enabling learning gains.

The importance of community could also be seen in a broader sense than just at the case study university library makerspace. A learning community could be seen to some extent building among the local universities around makerspace activities. Hazel and Maddie mentioned cross-university maker-learning professional connections and ideas sharing. Hazel described a 2018 workshop for biological sciences and biotechnology with attendees from a local university involved in makerspace training on how to use 3D printers and developing 3D learning models (essentially puzzles) of real-time biological processes for POGIL activities (as mentioned previously POGIL, 2020: Process Orientated Guided Inquiry Learning, a Constructivist approach to learning). This workshop also addressed inclusivity issues and involved a collaborator from another HEI in a nearby state who was an expert on accessibility and universal design and who talked about how to make models usable for everyone. Charlotte remembered that ‘they were here a couple of days and then over the next year they worked . . .with our undergraduate research students on further developing their projects and implementing those in their classes’ (AC/STEM/1). She and Miranda described how they had published two papers on this workshop, and also created a website with the distance education department of the university to share the 3D-printed models and associated lesson plans. Charlotte said the website,

> is set up so that someone can publish just a 3D print, a lesson plan, or both. And then you can . . . do what they call remixing... maybe there's a model that you see, but the lesson plan that's with it isn't quite at the right level for your particular class. So you could create a new lesson and upload that attached to the model as well.

Accessibility issues were also addressed with these scientific models through using different colours and braille systems for different parts addressing inclusivity issues for dyslexic students and those with poor eyesight. Filaments were also used as part of the 3D models to create easy flexibility within models often employing electronic, magnetic, moving and interlocking parts.

Although there was a general sense of a makerspace community in the broadly welcoming manner the library space exhibited, the idea of more established communities forming around this makerspace was contradicted by Colin's observation that student or staff maker groups around particular interests were yet to form. In terms of communities of practice around particular makerspace technologies or activities there was not much evidence of this at present in this case study. However, Mariana did mention some attempts to start new communities: 'I know of one staff member who is attempting to get a… making-club up and going' (PRO/STU/HUM). She also reported that some clubs already in existence found they had an affinity with makerspace activities (e.g., the textiles club) and have formed partnerships with the library makerspace service. Thus, it could be seen how further work on community building around particular activities and technologies to specific interest groups could further enhance inclusivity aims potentially reaching beyond the university.

8.3 Social learning support

Although clearly defined learning communities across the broad spectrum of interests possible in maker-learning may not have been established at the makerspace, it was clear that ad hoc and course-based social learning was integral to the maker-learning occurring at the case study site, and 'inclusive' in the sense that all participants felt the library makerspace was friendly and welcoming thus dialogue between students was common. Much of the learning I observed was social, including learning within the ZPD. All of the students I spoke to across disciplines had undertaken problem-solving and prototyping activities as course-related library makerspace activities, which involved students working together in small learning groups requiring dialogic forms of creative thinking. For example, Rachel described her experience during the First year Engineering Design Day (FEDD) where a list of problems were presented to students often from different courses to choose from, and everyone is required to undertake a library makerspace induction. Rachel's team used the space to make something a family can take on vacation that has multiple uses. The team designed and 3D printed a karabiner for a camping trip which had multiple uses as a compass, a ruler, a bottle opener, as well as a clip.

8.3.1 'A sort of nexus'

Academic participants from all disciplines were keen to emphasise the usefulness to students from all courses and backgrounds of working with the makerspace staff whose expertise they valued: 'they do work directly with our research students They spend a lot of time in the makerspace working one on one with the makerspace staff, and I believe really learned' (Charlotte/ AC/STEM/1). The learning Charlotte identified as being primarily around the technologies required for the particular coursework or project. However, this learning about technologies was often seen as more than a simply instrumental process, although support with technical skills and troubleshooting was important, e.g., 'I think having experts on hand to troubleshoot is the most important, students ......do need to complete a project' (Maddie/AC/HUM/2). Academic participants described a kind of interpretive collaboration between library staff and academics/students that took matters beyond basic IT support for solving immediate technical problems, to more creative and innovative possibilities through establishing shared areas of common understanding and value exchange with different kinds of students. Maddie testifies to this:

> I think that the library has a bigger picture of you; IT is very focused on solving a problem… and not necessarily good at communicating how tools could be used by humanists in interesting or new ways. They're not interpreters.

Maddie described her puppetry project where students were required to 'remediate' some graphic novels into shadow puppetry, as one where the makerspace service provided an opportunity to support a 'quirky' project popular with her students in an inclusive manner. This was a project that Maddie felt other professional service areas and many academic colleagues may have been too risk-averse to help with.

Other examples of unusual projects looking at diverse types of learners included Peter who was inspired by Digital Humanities/Critical Making projects employing reflective design in bibliography and textual studies such as Hancock *et al.* ('Bibliocircuitry and the Design of the Alien Everyday', 2013) which highlighted 'experiments to create basically augmented books with ... circuit stickers and other kinds of connective materials as well as messing with the structure of books' (Peter/ AC/HUM/3). The intention of these experiments was to use objects to think with (Hancock, 2013), in this case 'the book as a media object' (Peter), in a design-orientated way to imagine futures as well as reconstruct understandings of the past. For example, Hancock *et al.* discuss work on increasing the affordances of a book to make it a more interactive experience, in this case creating a multi-modal reading space for Coleridge's 'Kubla Khan' incorporating Makey Makey technology. By touching graphite markings in the book a circuit is completed and triggers a pre-recorded audio track from software running on a computer, drawing in complementary music to create a particular reading mood and critical commentary. In regard to this kind of learning Peter made the relevant comment ‘I will not discount the pedagogical value of cool’. In this project example we see how more traditional humanistic interests and material culture can be connected to more modern online culture and technologies to create new perspectives potentially of interest to humanities and social science students.

A driver for this growing cross-disciplinary ‘nexus’ trying to reach out to *all* student types in an inclusive manner is Chris’s work as Experiential Learning Librarian, which involves consultation with academics from different faculties where they describe their courses and learning objectives and Chris sees what library services, including the makerspace and others (e.g., VR, Digital Media Lab, Special Collections), will work well with the course. Chris cited Maddie’s puppetry course project as an example of how the socially constructed interpretive process takes place between library makerspace staff, academics and students. He explained how you can also teach different ways of doing things from an awareness of the use of a single tool. Chris explained how in the makerspace students from all disciplines and backgrounds are encouraged to try new things and do things differently, but the technical process can be similar for different outcomes. This awareness can be achieved by showing how different tools can use a similar design process (e.g., laser cutter, Cricut cutter, or the digital embroidery machine) and often the same file type (e.g., SVG) to achieve different processes and objectives, covering all student needs.

8.4 Driving inclusivity aims

I saw how the makerspace aimed at creating an inclusive environment through my observations of the many different types of makerspace activities. It was clear that, for makerspace beginners, initial instruction and encouragement was important, as I observed students from different faculties on the ‘build day’ morning of the 22 of September 2019. The teacher encouraged communication and risk-taking by telling everyone they would not be doing a ‘high stakes’ activity, unlike more target-driven learning elsewhere on the course (no summative marking was involved). Students had been asked to make a media object that was meaningful to them and then write a short paper about it. Mariana provided an introduction to Tinkercad (an-easy-to-use CAD design tool) which most of the students then used to create 3D designs. Mariana explained the basics of the process with 3D printing, including details on exporting to STL files, sharing build plates for smaller options, filament needs, print cost in grams, thinking of support needs for the 3D object so it does not fall apart, and standard as opposed to high-detail prints. Mariana was then busy answering questions from students in a more in- depth, interpretive and co-constructive manner, mainly about 3D printing for particular projects, and also helping one student to employ sewing for her work. Thus, as I have shown, the library makerspace inclusivity service agenda was built around creating a friendly space, welcoming students from all disciplines and backgrounds who may have an initial (very) low technical skills base and scaffolding support in different forms to suit different student and disciplinary approaches to learning (including 1:1 or group support in the space during activities, generic and course specific maker-learning teaching and training and more in depth 1:1 support). This open, friendly inclusive approach was clearly a good place to start but the service had yet to develop many ways of targeting specific students from less privileged backgrounds, a point acknowledged by Maria who wanted to use her own background more to talk to students who may have felt the makerspace was an alien middle-class phenomenon that they would not have come across prior to university.

However, there were some more proactive examples of efforts to engage with diverse student identities which I now go on to discuss.

8.4.1 Representing diverse student identities

I observed some clear examples of engaging with diverse student identities. An example of a kind of material/conceptual transference Hazel saw of value in terms of diversity could be seen in a project she mentioned that involved a student with medical issues who became interested in the idea of wearables as a way of

> expressing the kind of human dimension of medicalisation. What it felt like to discover you had a medical condition, and she created this … skirt [with] all these little pockets and you could unclip the pockets and as you did lights came out of the pockets (AC/HUM/1).

The library makerspace was used to work out how to stich LEDs into the garment. This example shows how more artistic and philosophical endeavors can be part of the conjunction of crafts and technology in maker-learning. As the philosopher Alva Noe argues about John Dewey's understanding of the nature of art, citing Dewey, 'art is experience, for Dewey. Artists don't make things. They make experiences … Artworks give you an opportunity to enact the ways in which our lives unfold' (Noe, 2015, p.205). Thus, Hazel's makerspace project example is of an individual's lived experience of illness expressed in an artful material manner. The viewer is drawn into an understanding of the human experience of something previously hidden (the illness), that has now become apparent, and offers a strange and disturbing fascination whilst creating a space within maker-learning to express diverse identities around the experience of illness.

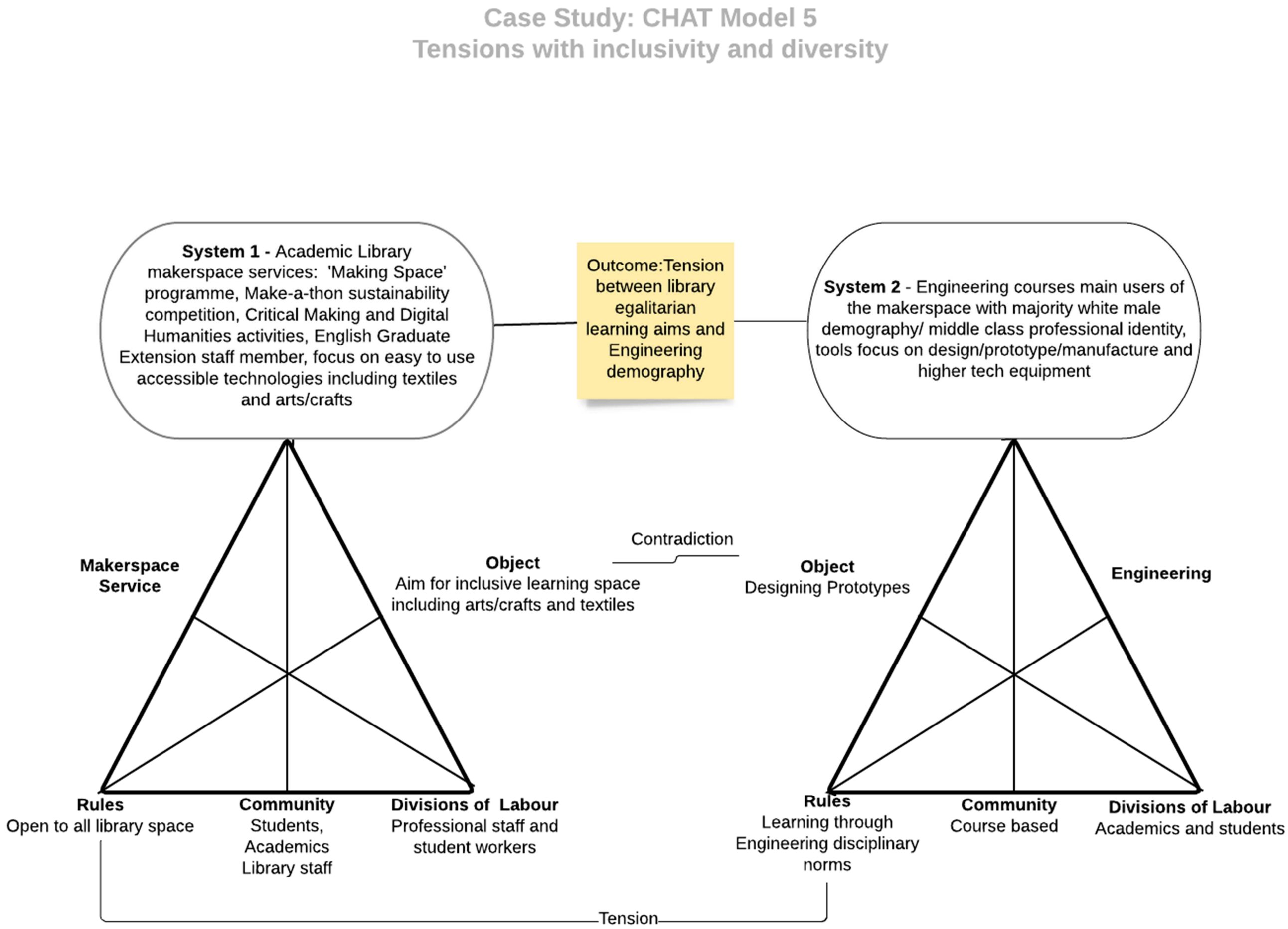
8.4.2 Meeting the diversity challenge

This chapter now looks at how this academic library makerspace has tried to further meet tensions and contradictions within the inclusivity challenge, by proactively endeavoring to create a more diverse maker-learning community in terms of issues of gender and race within STEM disciplines. The key sub question is:

> Is the lack of diversity in STEM addressed by this library makerspace service, and if so in what ways is this aim achieved or hindered?

As was clear from academics and students' interviews, library service efforts to make the library makerspace inclusive had met with some success but there was still much work to do. Engineering was the main user of the expanded library makerspace service at Campus 2, with the typical Engineering demographic of mainly white male students. Tensions in this case study between the library's egalitarian aim of creating maker-learning opportunities for all and the Engineering dominant reality at the time of the research are illustrated in the final CHAT model (5) below which illustrates this important problem space that will be discussed in this section.

Case Study CHAT Model 5: Inclusivity and Diversity



8.5 Beyond STEM?

Peter highlighted how Critical Making and the decision to avoid restricting the makerspace activities to high-tech 'glitzy, beepy, blinking' (AC/HUM/3) equipment was key to increasing diversity as it attracted students who were not from engineering and even 'anti-engineering' who were therefore less likely to only be white males. He also described how the inherent tensions about who gets to be a maker and the cultural baggage of the maker movement became a critical point of learning from the start for his maker class students. The students were shown 'this utopian 3D printing video about how 3D printing will change the world and then we read an article … in the *Atlantic* by Deb Chachra who's an engineering professor, called “Why I am not a maker” that goes some way to exposing the ideology of making itself’. As highlighted in the literature review, Chachra’s 2015 article critiques maker ideology as perpetuating the higher cultural value placed usually on making and engineering type activities (usually construed as male) over the caring and nurturing activities more associated with females. Although Chachra’s use of stereotypical male/female traits can itself be critiqued, she still points to a possible bias in maker culture within the Academy. Thus, potentially even calling this type of technology-enabled learning area a ‘makerspace’ may be seen as obstructive in itself in terms of inclusivity.

However, Peter pointed out that inventing new names all the time for similar things can be problematic: ‘you run into problems with conventions, you can’t make up words and expect people use them in language, and the whole “let's invent start up names for our things” never lasts’. If maker-learning is often associated with STEM as I have shown, there is still perhaps room for an interesting dialectical challenge within maker-learning in HE to expand the concept rather than give up on it. Students can become increasingly confused by concepts picked up across learning domains when these terms are differentiated primarily as a rebranding exercise by those keen to coin a phrase and make a reputation in the knowledge and language games of ‘the Academy’, without always ‘explicitly’ (to use Brandom’s term, 2000) and clearly defining the new term/concept. This confusion generated by whirlpools of competing discourse is particularly apparent in shorter-lived academic movements that create language soon forgotten. However, a new name *might* be more appropriate with a new concept for a technology enhanced learning space that genuinely takes it away from established maker-culture to a clearly defined extent. Peter cited the example of the Scholar’s Lab at the University of Virginia where ‘scholarly’ making activity is the primary focus. This

Scholar’s Lab focuses specifically on Digital Humanities, Spatial Technologies and Cultural Heritage.

The question of whether more critical views from different perspectives can be accommodated within maker culture is being played out within academia. Key elements of the data from this case study such as the perspectives of Hazel on digital literacy, critical making and new materialism and Peter’s emerging critical but still engaged views of maker-learning I have outlined suggest that a broader, more inclusive view of making is possible within a university makerspace. Peter gave the example of using the library makerspace for a class on ‘steampunk’, a genre of science-fiction that employs historical settings and steam-powered machinery rather than privileging more advanced technology:

> [The teaching in that class] argues that steampunk is a kind of hacking of these normative structures of science-fiction history potentially for the inclusion of marginalised positionalities, then we go to the makerspace …to make a steampunk object as an object to think with. (AC/HUM/3)

This activity also connected with a visit to a local scrap exchange that itself challenged the casual approach to sustainability of many makerspaces. The scrap exchange was full of interesting thrown away items. As Peter explained, ‘we bring stuff in, we actually went on a shopping exhibition with [Adrian] and [Daniel] and supplied a lot of things to students … if the makerspace emphasises … these kinds of recycling, bricolage rather than … innovation, [or] glitzy things, it probably has a better chance of opening up to different kinds of persons’. Thus, we can see how inclusivity can be encouraged through a sustainable, low-cost DIY culture.

Hazel gave examples of how English students, who previously may not have considered engaging with maker activities, could be given the confidence to do so thus encouraging more diverse maker-learning identities. Through the example of a library makerspace-hosted wearables workshop, she explained how learning gains were achieved. Students learnt on a basic level how electricity worked with light sensors and acquired the confidence to use different materials in their work. At the end of the session students got to keep their Arduino Gemmas (a miniature wearable microcontroller board). She also highlighted her views on the particular value librarians brought to supporting her students. ‘Librarians have an open an expansive understanding of how to interact with [you] and share knowledge, librarians want you to know things and they work hard to help you to know things’. This perspective showed a perceived tension with IT departments’ more functional concerns of making technology work in a secure environment: ‘their job is to lock everything down and to control it, for good reason’ (Hazel). An interesting contradiction between these key professional services was highlighted when I asked her, ‘so, if IT services are a service, who are they serving?’ and she replied ‘The State’ [as in a governmental entity]. When asked the same question about the library the reply was: ‘The citizens of the state’. Hazel considered the combination of relational expertise and information skills with the inclusive/egalitarian need to serve all citizens by providing alternative teaching and learning modalities for students to be the key benefits from the library-hosted makerspace, and from librarians taking a ‘material turn’ in their professional practice. Peter was also keen to emphasise the possibilities of ‘intellectual partnership’ with librarians that the makerspace service afforded: ‘some of them [librarians] have a relationship with the students ongoing through the projects … My hope is the students take away a sense of the library as a possibility space beyond … a book service in whatever mode, digital or paper’.

In all cases of trying to advance beyond STEM inclusivity and diversity aims relational work was key. Daniel described how the relational agency required for encouraging wider academic use and intellectual partnership with regards maker-learning was sometimes about finding a common knowledge about what learning outcomes are valued with different disciplines involving digital literacies, rather than specified knowledge about particular technologies. Mariana made a point that ongoing inclusivity and diversity goals could also require relational expertise and agency in reaching out to alumni: ‘a lot of people tend to get sad when they know they're graduating because they are no longer able to access the space’ (PRO/STU/HUM). Leaving students have asked if there is some kind of alumni programme where they could pay monthly. Mariana acknowledged that the makerspace would need to be larger to accommodate this wider group. She also wanted to see more outreach to the local community, if possible, to ‘hopefully create more inclusion’ in terms of reaching out to disadvantaged communities including ethnic minorities.

Mariana, who came from a ‘majority minority state’ (a US state comprising less than 50% non-Hispanic whites) with many socio-economic issues, was used to interacting with students from non-privileged backgrounds, some of whom would have been homeless, and was very much prepared to help disadvantaged students. She felt more could be done to reach out to these kinds of students at the case study university who are unlikely to identify themselves as makers: ‘I have not encountered as many of those students on campus, even though I know they exist. So I'm not really sure the best way to approach that’. We can see how these statements highlight the difficulty of gender stereotypes in relation to maker-learning, the apparent invisibility of minority students and despite clear progress the current lack of a clear strategic path to challenge inclusivity and diversity issues that seem to be embedded in maker identity.

8.5.1 Challenging the importance of Maker identity

It thus becomes apposite to explore how HE-based maker-learning may challenge and perhaps form new maker identities. Although some of the students interviewed identified themselves to varying extents as makers (Nathan, Rachel, Ivy) there were caveats. Ivy, for instance, saw herself as an ‘invisible’ part of maker culture in the literal sense of being interested in it but not taking active part in any communities of interest, whilst Nathan had a long history of making and tinkering pre-dating his awareness of the maker movement. The importance of not putting people off with overuse of the maker identity was reflected by Chris: ‘I don't talk about I'm a maker, you're a maker, we’re all a maker “woo” because I don’t think that's useful. I think it's much more useful to talk about “what would you like to do?”’ (PRO/LIB/2). He felt that, although some student users would self-identify as makers, others wouldn’t, and in the student population as a whole the majority of students would not describe themselves that way and would not necessarily be confident in embarkingon maker activities. This is where he positioned the importance of course-related maker work that could bring in non-maker students: ‘course instruction is so important because it brings everyone in across discipline. We reach a bunch of people who would not normally think of themselves as a maker … we’re really helping to lower that barrier and provide access’.

Data shared showed a diversity of well attended, course-based sessions and workshops beyond engaging with engineering students to reach more ethnically and gender diverse humanities courses. ‘Technology in the Arts’ is currently the second most delivered of these; in recent years ‘Sewing Basics’ and ‘Getting Started with e-Textiles’ have been among the top ten workshops alongside more commonly found makerspace workshops such as 3D printing and Arduino although specific data on the ethnicity and gender of participants was not available. In addition workshops with a social justice angle were being delivered, for example, ‘Critical Making for Sustainability’ and the yearly sustainability focused “Make-a-Thon’. The position of a female humanities-based Graduate Assistant was also described by professional staff as a deliberate attempt to anchor the space in a way that would attract students beyond the expected engineering cohorts.

8.6 Library diversity affordances

Ivy felt the library makerspace had more to offer in terms of diversity and learning affordances than other types of makerspace. Comparing her experience of a local makerspace that positioned itself as a prototyping and design-assistance space for technology-based companies which she visited for a task and quickly left, with the university library makerspace which she used more, Ivy commented that the library location made the makerspace more accessible as she could do her 3D printing and then ‘stick around’ and do her homework, get a book, or use a computer. Mariana described how empowering the library makerspace could be for women using the space, giving the example of a friend whose father always got her brothers involved in maker-type activities but not her, who now gets excited at the opportunity to make things herself. Rachel also mentioned how empowering it was for her to escape her family’s bias that maker tools were for boys, and now be able to use more ‘serious’ equipment herself. She was less interested in activities that are traditionally gendered as female such as sewing, thus showing that simply promoting stereotypically feminine activities such as sewing could be counterproductive. Rachel also felt the library makerspace encouraged smaller projects with accessible and easy to use equipment, and always making an effort to attract people with fun activities such as Halloween-themed projects.

Although the majority of support services scaffolded around the makerspace were focused on course-related workshops and sessions, there were no restrictions on students coming in do their own 'passion projects': 'because we feel like what the student learns in pursuing their passion projects really complements what they learn in their academic studies, and also potentially provides them with skills and strategies to tackle academic projects' (Adrian). As well as allowing diverse opportunities for developing skills and strategies for academic studies this 'passion'-based learning fits in with required twenty-first century career skills aims. For example, freedom to learn and develop on the student or employee's own terms fits in with the IT related concept of skunkworks, which is found in many more innovative companies, whereby there is an allowance and support for personally intriguing projects that often end up in worthwhile marketable products.

8.6.1 Accessible technologies

The focus of professional staff on getting technologies to be used in the library makerspace was on accessibility. Thus, equipment and the accompanying user-education materials was chosen for simplicity and ease of use, which contradicted the culture of other, more specialised, makerspaces on campus. For example, Chris described the process of critically appraising reviews of new maker technology, giving the example of Mayku, a foam box vacuum former. It was affordable at $500 and 'it presented some really interesting capabilities that we knew would just be useful and a good fit for this space'. This tool allows for 3D models to be made of materials other than plastic through a process in which a 3D model is printed, then a vacuum formed around it, leaving a negative that users can cast using materials such as concrete or silicon, or even food such as chocolate. Mayku has an accompanying STEM educators' handbook, a user manual and accompanying videos. Chris explained its value, 'all of those ingredients and we'll say ok this looks like a good thing for us to try out and so when we got it ... I think one of our students was the one to work really in depth with it, and that's the case because we can delegate that they have time to do it'.

The accessibility agenda with new technologies also extends to lending out equipment and being the only place on campus a student can check out equipment regardless of their major (loans are mostly between eight hours and seven days). I found the space to be not obviously gendered in any way on my visit. This was achieved through the use of large, good quality wooden worktables that were kept clear of tools (thus dispelling any preconceptions of particular tools always being prevalent) after activities. As mentioned previously, it was clear much effort was made to keep it as tidy as possible at all times, including obviously labelled tools put on the wall and materials in clearly and simply labelled drawers. Although 'accessibility' and 'inclusivity' are intellectually distinct, the latter the broader concept, it is clear that without basic accessibility needs being met, people from all kinds of disciplinary and cultural backgrounds may be unnecessarily excluded. The managers have tried to address this.

8.7 Intersectional challenges in growing the user base

Despite the many efforts outlined to create an inclusive space the ongoing tension around diversity was apparent in terms of the often-intersectional challenge of attracting female, black, poor students when Mariana described how the makerspace could be very white/ male/middle class dominated at times becoming a 'bro' space, and that the breakdown of staff support at only four females to seven males was not always helping. Chris thought that, although not enough data was available yet to tell definitively, the library makerspace was predominantly used by white males. Thus, Chris wanted to see more purposeful activities inviting groups that would not normally consider using the makerspace.

Mariana, using her own background as a Latina growing up in New Mexico as an example, discussed how, although she was aware of maker technologies such as 3D printing, she had not seen it other than on videos. Being acutely aware from her own cultural background of when students might find the makerspace alienating has led her to be very proactive in her approach with new students who might want to use the space, sometimes seeing students stopping at the threshold before coming in, and going out to greet them and see if she can put them at ease. She could see certain subject-based student groups, such as those from English, Business or Sports Management, were intimidated at first in the makerspace. For her, teaching students from all backgrounds 'soft' as well as technical skills in the makerspace was important: 'when I teach orientation, there's one point where it says … be able to ask for help and also help others. And so I reframe it as … be a self-advocate and then an advocate for other people within the space'. Seeing her teach an introduction to the makerspace session to a variety of different students (Makerspace 101, 21/10/19), I noted that her emphasis from the start was on inclusivity and diversity and on the fact the space was open to all.

Mariana felt that the expansion of the makerspace to include more materially based, older technologies, such as sewing rather than digital-based making, could increase the diversity in the user base. She mentioned the relatively new embroidery machine: 'I do think that there's sort of a resurgence in thinking critically about the domestic arts and people are doing all sorts of counter-cultural embroidery. So … it ties in with … reclaiming some of those gendered productions and textiles'. This 'reclaiming' was being promoted in training sessions aimed at male and females in a deliberate attempt to open a non-prejudiced horizon of craft-based activities for all. Miranda also described how staff supporting the space could help to encourage more inclusive and diverse ideas for teaching and often provided ideas that academics would not have on their own.

The ‘Making Space’ programme was designed by the library to specifically address issues of inclusivity and diversity in entrepreneurial maker culture: ‘Through a series of public talks and workshops, the program series centers gender diversity and inclusion in STEM, as it intersects with race, ethnicity, ability, and sexuality’ (this and following information/quote from document promoting the Making Space programme, see Appendix 6). There was some limited initial data available at the case study site on the success of the programme that was encouraging: 2016 data showing more inclusive makerspace activities included a Creative Coding Workshop (70% female, over 50% humanities and design students) against other data showing the typical male STEM bias such as a Creative Coding Hackathon (90% male, 80% computer science students). However, a Creative Coding lunch group showed a 50/50 female to make ratio. While I was there, the designer of the Rap Godz board game, Omari Akil, provided an inspiring talk on moving from a computer science career into board games, trying to challenge the white hegemony seen across board game culture with a new game designed for an audience with an interest in rap music history and culture. After the talk the large, diverse audience was invited to the makerspace for a ‘Hyper speed Game Design Session’. Activities such as this provide clear evidence of how this, and potentially other academic library makerspaces, can widen participation and interest in maker-learning through a broad cultural programme of maker-related events. Thus, we can see how maker-learning programmes in HE could be used to combine strategies around race, gender and access. With more opportunities for people from BAME and LGBTQ+ backgrounds to be invited to talks in an HE makerspace with a follow-on activity, the more normalised this kind of activity space can become for a diverse range of learners.

8.8 Summary of Chapter 8

This chapter has focused on the level of inclusivity this makerspace service has achieved through looking at maker-learning through different identities. Challenges examined included the nascent maker community growing around the space, and the current lack of CoP around particular technologies and activities identified. The inclusive value of the social learning in the space has been clearly evidenced, including the fact the majority of information needs from students from all courses and backgrounds are either met by peer-to-peer interaction often across disciplines or conversations with makerspace staff where a practical/interpretive approach to specific learner needs can be addressed. Thus, in this case study I observed the evolving role of academic librarians in the makerspace context as interpreters of diverse and constantly evolving academic and student needs. The bridging of information and learner needs to new constructivist and critical pedagogies, and through this more diverse student backgrounds and identities, is becoming increasingly valued by academics in this maker-learning context. The particular value of the non-STEM perspectives of Critical Making and Digital Humanities encouraged in library training and academic partnerships is shown as a useful counter to STEM dominance. Most notably, in terms of library-led activities encouraging diversity, the Make-a-Thon and 'Making Space' programmes are looked at as ways of encouraging students from BAME and LGBTQ backgrounds to engage with maker-learning.

However, the main users of the makerspace are still mainly white male engineering students, so there is still much to aim for. I have learned through my analysis that maker identity needs to be challenged in an HE context, as it was from the Digital Humanities perspective in this case study where two competing views of being a maker (the professional engineering-focused maker-identity and the culturally diverse art and design welcoming model) clash. Chachra's (2015) cultural critique of how the embedded sexism of STEM learning can too easily transfer to all maker-learning environments is a clear challenge to anyone trying to set up an inclusive maker-learning environment. There is an opportunity for academic libraries to provide more diverse maker-learning spaces, but more understanding and modelling through building common knowledge of how this could work from those scaffolding maker-learning (including academics, professional staff and students) is required. I now go on in Chapter 9 to present an inclusive, critical and humanistic vision and model for critical maker-learning in HE-based onmy research and analysis.

Chapter 9 A model for developing critical maker - learning in HE

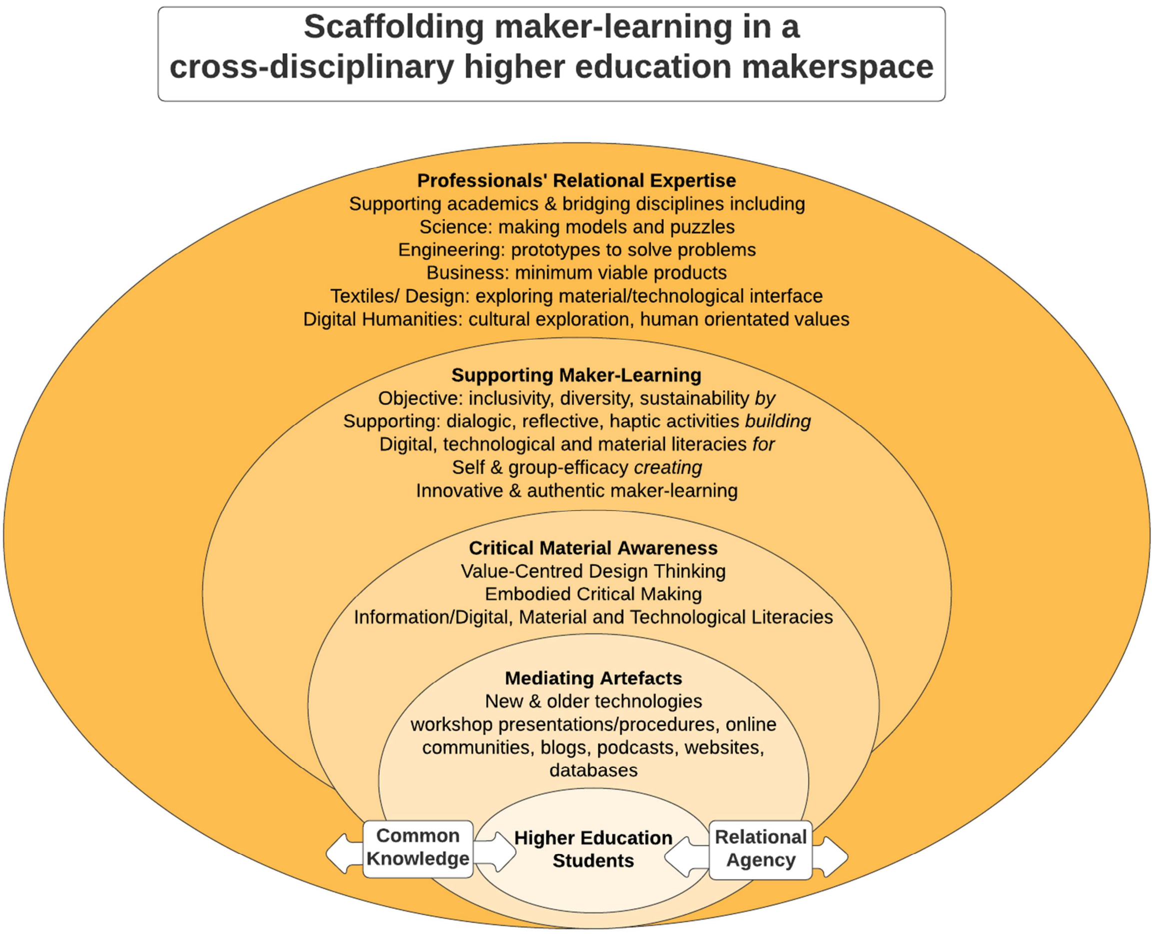
9.1 Introduction

It is clear from the emerging literature and research, including mine, that there is much enthusiasm from participants in maker-learning in higher education. However, there remains a key area of critical concern regarding its ongoing potential in HE regarding how it is engaged across disciplines. In discussing maker-learning with academics and professional staff outside of the admittedly large and expanding number of educators already involved in it, I have often found it is difficult to explain the particular value of maker-learning as an expansive and critical educational tool. In the first section of this chapter, I present a model from my case study research to build cross-disciplinary maker services as socio-critical, empowering learning spaces for all types of students and academic perspectives. The model is built from layering my analysis from previous chapters in an abstract conceptual form for transferability to different contexts. Thus, through the collective insights of my research participants and my analysis of what their observations could mean in terms of creating an ambitious, inclusive, critical, cross-disciplinary space I present a model for scaffolding HE critical maker-learning. This model is designed as a platform for people to build their own socio-critical consciousness through critical scientific *and* cultural/material awareness. My framework model is followed by a detailed explanation.The second section of this chapter looks at how my model could be applied more broadly to across-cultural academic library maker-learning movement, using potential developments in the case study maker service as an example.

9.2 Scaffolding Maker-Learning in Higher Education

To advance the conversation within the Academy around the possibilities of maker-learning in higher education (HE), I have taken key insights from my analysis of the problem spaces I have explored through the CHAT framework in this case study to build a model for further scaffolding maker-learning in HE. This model is designed to be used across teaching, course design, assessment, and accreditation frameworks and systems for the transmission and co-construction of disciplinary and cross-disciplinary bodies of knowledge. The inherent push for HE within this model is the need to design learning opportunities on all courses for a degree of self-directed interest-based projects, as well as fully accredited course-based learning, on all courses engaging with maker-learning:

Model 1: Scaffolding maker-learning



9.2.1 Makerspace: Mediating Artefacts

In what follows I will provide a detailed explanation of the model from the HE students at the centre, the mediating artefacts of the makerspace, my educational concept of Critical Material Awareness that expands the possibilities of maker-learning and the importance of common knowledge with professional's relational expertise and relational agency creating an effective cross-disciplinary makerspace.

At the centre of this model are the higher education students, as the key component of maker-learning whether acting individually or in a group, their interests are paramount. Common knowledge can be initially built through professionals exploring the affordances of technologies (mediating artefacts) in the makerspace, hence the two-way arrows showing common knowledge and relational agency building through all areas of activity. Thus the outer layers provide ideas for scaffolding designed to support the learners' self-defined journey. Rather than providing a narrow indoctrination to a particular learning paradigm or static knowledge base this model looks to show how learners can build self and group-efficacy in critical maker-learning across disciplines in a new site of intersecting practice. Drawing on Cultural-Historical Activity Theory engaged with in this thesis (CHAT, Engeström, 1987), the next layer to the student are the mediating artefacts of the makerspace including new and older technologies and tools, workshop presentations, online support from product websites and communities of interest and evolving practice including blogs and online fora, maker project plans, and makerspace rules including essential safety procedures and device instructions. Here the support of professional and paraprofessional service staff (librarians, IT, learning technologists, student helpers) helps to engage students with the learning affordances of the makerspace in the ZPD between the learner and library support or between learners utilising the similar technologies. I have emphasised in this thesis the particular value of relational agency (in this case from Adrian, Chris, Daniel and Mariana) in developing new services around Critical Making and Digital Humanities with academic staff and students (see previous chapter) that can bring an open, inclusive service ethos. The service provided by the academic library service scaffolds interpretive project support using subject and digital expertise, traditional library-based logical/organisational support and (critical) information literacy teaching to the maker- learning process. However, not everyone in an academic library service will have the necessary technical skills to support the makerspace. Collaboration with IT or Learning Technologists will most likely be required.

9.2.2 Critical Material Awareness

Surrounding this ring is a layer I have called Critical Material Awareness. On reflection, the part of my professional interest drawing me to academic library makerspaces that has provided wider horizons of possibility through this case study concerns the link between the morally concerned constructionist pedagogy of Critical Making (Ratto, 2014) as promoted in sessions at the case study site and the ethos found in Critical Information Literacy: 'the library profession can strive to recognise education's potential for social change and empower learners to identify and act upon oppressive power structures (Tewell, 2015, p.36). When I give introductory information literacy sessions, I often encourage students to ask some basic questions about who has created the information and why it has been created. This also leads to consideration of whose voices are not being heard as we see in many cultural phenomena including maker-learning (as I have shown in the previous chapter) in the critical intersectional challenge to white/male/middle class maker-identity. It can quickly be shown how information that is sometimes portrayed as being based on apparently 'objective' research can be problematised, by subjecting the spin from powerful organisations and individuals with particular agendas to rational analysis. Critical Information Literacy library pedagogy can find fruitful engagement with Critical Making as both are underpinned by the Freirian notion of empowering the learner's agency from the start of the educational process through an experiential approach, in which one quickly learns to think and act for oneself in a critical cross-disciplinary manner. From a sociocultural, realist perspective, cross-disciplinarity is important to the development of critical theory as it provides a more holistic and in-depth understanding of reality whereby humanistic, technological, scientific and economic considerations can be drawn together in a pragmatic understanding of current issues and how change might be practically aimed for:

> The truth is: regardless of what society we are in …it is impermissible to train engineers … nurses, educators or mechanics, farmers or philosophers … without an understanding of our own selves as historical, political, social, and cultural beings- without a comprehension of how society works. (Freire, p.116, 1992)

Hazel’s observations in this case study highlight the environmental concerns from some regarding too much maker activity (p.147), suggesting ways that a librarian's critical teaching could usefully expand its scope to include critical cultural/material awareness even without maker equipment being available, something currently potentially of interest as part of online learning models given the Covid-19 pandemic locking down much face-to-face activity.

However, the embodied nature of maker-learning has a particular educational value and can reinforce cognitive awareness of technological and material affordances. Thus, the mediating material artefacts of makerspaces could become a useful physical toolkit to extend Critical Information Literacy teaching. An expanded idea of Critical Information Literacy that takes on board recent insights from Critical Making and Digital Humanities and demonstrated in projects looked at in this case study (e.g., Peter’s students linking surveillance technology with written texts, Chapter 7) could start to bring the 'material' into conversations to escape a narrow cultural focus on written 'texts'. For example, a lesson could include a simple exercise where students consider what are the social, economic, environmental and political implications for all the material components making up an iPhone, including getting to handle components of a deconstructed phone, thus adding kinesthetic and haptic to theoretical awareness (as with Peter's Steampunk examples of recycling bricolage showing how we can re-cycle under-valued 'waste', p.160). This kind of maker-learning innovation could be effectively combined with a more traditional trawl of recent journal articles about the socio-economic impact of the i-phone. Students could also try to source information to find out how *their* particular phone is put together, discovering who may benefit or be exploited as part of this market process.

Freire's (1970) criticism of the notion of students being taught through a 'banking' model of education where they are seen as empty receptacles for the materials presented by their teachers can be seen as the opposite of the maker-learning I propose with its sensitivity to individual passions and a critical material-based curiosity encouraged. Although the academic library makerspace in this study cannot be seen in a *radical* emancipatory frame, there were still opportunities within it for more choice and self-discovery in the learning process, moving away from that restrictive mode of education that Bourdieu calls 'being-for-the- teacher' (Bourdieu and Passeron, 1970, p.111) whereby student learning may be constrained by strategically kowtowing to restrictive pedagogic norms and sometimes overly restrictive 'learning outcomes'. Thus the self-motivation of all the students I spoke to, to make, create and apply their new knowledge to their own aims can in itself be seen in a positive critical light:

> We need learning environments that invite, excite, and inspire learners … Any effort intended to unlock human potential that is predicated on a content-transmission idea

will prove ineffective. (Barab et al., 2020, p.133)

Therefore, in the Critical Material Awareness layer, I have combined the Critical Making (Ratto, 2014) and value-based Design Thinking (Cockton, 2006) found in this case study (see Chapter 7 for discussion) with scaffolded maker-learning support from teaching (critical) information, digital and media literacies, and technological, cultural awareness and skills. Although Critical Making can be admired for bringing sociotechnical awareness to the maker process, often in interesting ways when overlapping with Digital Humanities ideas, it can also be critiqued on the basis that the activities and outcomes of Critical Making may just remain curiosities within sections of the Academy. Ratto has argued more recently for Critical Making to move outwards from the purely academic in a more instrumental manner as 'all these activities have resulted in relevant academic insights and some impact (as measured by such things as citation indexes), none of them engaged directly with the sociotechnical systems they were intending to address' (Ratto, 2016, p.29). This move towards impact beyond the Academy is reflected in the work Ratto has done more recently with Toronto General Hospital creating 3D models of life-sized human hearts so doctors can closely examine aspects of medical issues before operating (Kleiner, 2019). This latent potential for Critical Making to evolve further both within and outside the Academy as a critical rather than neo-liberal example of authentic learning (Lombardi, 2007) that engages students in potential real-world responses to socio-critical issues of concern to them, could meet with many challenges. Within the Academy, Critical Making runs up against 'the traditional structure of academic disciplinarity' (Ratto, 2016, p.28). If the Academy is to have genuine 'impact' on sociotechnical society-wide goals, Ratto argues, it needs to 'remake the normative systems through which we carry out scholarship' (Ratto, 2016, p.29). A definition of my concept of Critical Material Awareness follows, this looks to build on Ratto's thought by looking to address the central tension of lack of current impact from Critical Making projects, by building a critical and practical concept that can be used as a pedagogical tool across disciplines.

9.2.3 Definition and discussion of Critical Material Awareness (CMA)

Critical Material Awareness is the ability to apply critical thinking to the social and environmental impact of the use of materials across all areas of human activity so that material literacy can be expansively developed in society. As an educational tool, this cross-disciplinary concept is relevant to all STEAM and Humanities perspectives. CMA can be taught abstractly as a concept either face to face or online but can be pedagogically reinforced by embodied/haptic interaction with materials in critical maker processes. These processes are undertaken with the practical aim of creating ideas and prototypes for new more sustainable products and technologies to benefit society.

Critical Material Awareness can be achieved most effectively by handling materials/ objects/technologies in classes as part of the logical cultural deconstruction of their full social and environmental impact or through problem-based projects in maker-learning environments aimed not just at awareness but also at solving local and global socio-critical issues. These aims could include practical ideas that can be trialed by scientific, government and industry collaborations. Critical Material Awareness is thus a potential key new pedagogic tool for the Socio-Critical Realism that could be beneficial across all academic disciplines and political perspectives to address the current climate emergency and the massive, global, cultural and scientific changes required. These changes are unlikely to materialise without the shared efforts of all academic disciplines in the educational process (potentially at all levels of education). As Corbin (2018, p.7) puts it: ‘The skill of the twenty-first century's great thinkers will not be cleverness in one particular discipline, but knowing how to use materials as a bridge between disciplines'.

Thus, the Academy can move fruitfully towards more influential support for green 'new deals'. This would involve working with the best of the private and public sector to create a sustainable 'circular economy'. Critical Material Awareness is therefore an educational teaching and learning concept designed to join other emerging seeds of hope and renewal in the struggle to respond meaningfully to the climate emergency through inclusive, sustainable activity-based projects: 'materials can help to expose the cracks in our ailing systems; because they have the power to solidify new norms; because they can make more preferable futures tangible' (Corbin, 2018, p.7).

9.2.4 Supporting maker-learning

The next layer of the model shows the many ways maker-learning can be professionally supported to be more inclusive and sustainable through haptic, dialogic and reflective maker-learning. This will always be contextual int its specifics to student interest and curricula foci at different universities. Thus, as I have argued in this thesis, academic librarians as cross-disciplinary agents and interpreters are in a strong position to build the 'common knowledge' (Edwards, 2017) of what matters in supporting maker-learning at different HEIs. Common knowledge as conceptualised by Edwards involves a patient process between professionals identifying what matters from different professional perspectives (as with Chris' work shown in this case study in the new role of Experiential Learning Librarian reaching out to faculties), and potentially combining areas of knowledge to enhance shared professional values, and hence achieve positive material changes to practice. In this model, common knowledge on maker-learning runs through all levels of activity as it also includes input and collaboration from students in their digital/material maker activities, encouraging dialogic cross-disciplinary learning, and reflecting on attempts at innovation whether successful or not (so there is no 'failing'). This open, supportive, experimental approach potentially empowers learners and builds self and group-efficacy (Bandura, 1997).

Another key element to maker-learning shown in the Supporting maker learning layer of the model that I have found in this case study (that is so far under-explored in the literature) is the embodied, often haptic nature of maker-learning. Thus, from my sociocultural perspective, I have argued how the haptic can reinforce and sometimes lead social and reason-based dialogic learning: 'what we do with our hands shapes the way things are seen, remembered,imagined, or generally kept in mind' (Radman, p.378, 2013) as with the practical enquiry- based learning model (POGIL, Chapter 7) adopted by Charlotte and Miranda. Although much maker activity is through a computer interface (e.g., 3D printing), much making also involves 'traditional tools', and sometimes a combination of the two (for example, a student I observed whittling at a cog made in a 3D printer with a Stanley knife to reduce excess material and make it functional). Even when the making activity is mostly done first on a computer, haptic learning is involved. The digital interface involves the hands (our fingers/digits as Hazel pointed out to me). Our hands are thus a key part of the process of using a CAD programme. We only have to look at the popularity of iPads and iPhones to see how the haptic can still interplay with, and sometimes lead, the rational in terms of digital capabilities and the learning process. The digital is also ontologically 'real', not in the absurd sense of an apple on the monitor being the same as an apple you eat, but in the sense of being part of a holistic view of a scientifically observable material reality and embodied human experience.

Also included in this layer are the key overarching themes of this thesis: inclusivity, diversity, sustainability and cross-disciplinarity that I have discussed in depth (see discussion in the literature review and chapters 7 and 8). The key elements of the common knowledge of professionals and academics who pursue these goals I found through my case study are therefore summed up through the operative keywords identified, encouraging, supporting and empowering students to take part in ethical, embodied, reflective, maker activities. This builds self and group-efficacy for undertaking innovative and creative maker-based projects. There will be many challenges to achieving these aims, perhaps particularly including the many ways makerspace can be harmful for the environment by using so many potentially disposable technologies**.** As discussed in the literature review Smith and Light's bringing together of different makerspace perspectives for their 2015 workshop study suggests ways makerspace services could get beyond the apparent double-bind of trying to justify maker-learning from a sustainability perspective, some of which were evidenced in this case study. These included creating awareness of technologies as something we can use in sustainable ways including repair workshops (as with the repair cafe carried outin the case study makerspace), prototyping sustainable designs and systems to support sustainability issues (e.g., an app detecting home energy wastage, an example from the sustainability-focused Make-a-Thon). Smith and Light (2016) also highlight possibilities around incubating upcycling businesses and 'organising workshops for the social innovation of local sustainability' (Smith and Light, 2016, p.2).

9.2.5 Professionals' relational expertise

The final, outside layer of the model shows how the different disciplinary perspectives found in this case study are connected by the relational agency and relational expertise (Edwards, 2017) of professional services staff (in my case study library staff and student makerspace workers). The potential benefits of disciplines understanding each other's perspectives are myriad. For example, engineering students learning from textiles and art/design students the importance of exploring the aesthetic possibilities of different materials as part of the design process. The sciences can learn from the more entrepreneurial focus on creating practically useful informative models and puzzles for learning that would be of interest to a wider audience. And perhaps all other perspectives need to be aware of the environmental and sociocultural awareness that can be enhanced through learning about Critical Making and Digital Humanities. As shown in this thesis Academic librarians (such as Adrian, Chris and Daniel in this case study who were all pivotal to the advances this makerspace service has made) are in a position to be able to help with efforts at cross-disciplinarity through information literacy support and interpretive cross-disciplinary relational work, including helping to guide understanding across disciplines and designing new ecologies of cross-disciplinary makerspaces that can be genuinely interactive. Academic libraries can also help students link to life outside the Academy through beneficial social projects with community, public library, school and museum-based makerspaces.

9.3 Service development to further scaffold maker-learning

I now go on to show how this model can be employed to understand how the case study makerspace service could productively evolve as an exemplar for how it might apply to academic library makerspaces more generally. This sub-question thus completes the CHAT based dialectics of this thesis in the ZPD between researcher, research participants and the expansive possibilities from the activities that were observed and analysed:

What are the main tensions and contradictions that need to be addressed for further development of the library makerspace service?

9.3.1 Agency and risk-taking

A key element of the relational agency that has enabled the library makerspace service at the case study site to develop to its current extent was the move to a closer relationship with academic colleagues, in terms of understandingwhat the makerspace might mean for their different disciplines. This has incorporated potentially very different perspectives (e.g., entrepreneurship and Digital Humanities). One area of agreement across disciplinary perspectives is the need to get students out of the potential restrictions of always being tied to more formal modes of learning (e.g., essay-based assessment) towards more alternative, polyvalent and stimulating ways of learning and assessment. The need to take risks was a common thread across the academic disciplines in this case study: whether as an engineering student experimenting with prototypes; an entrepreneur investing time and money in looking for market opportunities; science students spending time out of text-books, journal articles and lab work to design their own learning objects; textile students feeling their way through projects to understand the potentials of different materials; or English students stepping beyond the book to new ideas as to what a 'text' can be. As Maddie pointed out, with regards to her maker-learning related course projects, 'we ask our students to take risks, we need to also take risks' (AC/HUM/2).

The library makerspace enabled this kind of risk-taking and encouraged more creative, flexible teaching possibilities through carefully scaffolded support. Although there are no immediate plans to expand this library makerspace service, most research participants did think it would be desirable to expand the space to increase cross-disciplinary maker-learning affordances for all students. Adrian, for example, would like to install a new digital weaving tool which is not possible at the moment due to space limitations. Part of the challenge in expanding this makerspace service would be keeping standards high to meet the professional standards and values of the research participants I met. This means having enough library staff time to allow for professional agency to further scaffold support for academic and student needs, working closely with very different perspectives to interpret maker possibilities for learning. Chris's recently obtained role is tailor-made for further outreach, while also requiring a lot of ongoing teaching by him to support the workshops. The potential success of this role might lead to (arguably desirable) service tensions as the outreach becomes more involved and competing faculty demands emerge, possibly including course planning with academics.

9.3.2 Service tensions and professional roles

Although most of the research participants thought the makerspace needed to expand in terms of space and staff time, there were many potential contradictions between what different people would like to see happen. In the highly competitive world of professional services vying for money within HE, it is always necessary to have a clear vision of what more a library service could do with more budget and resources. My research found many interesting but contradictory ideas for how this library makerspace could develop and possibly expand. My theory for critical maker-learning incorporating Critical Material Awareness suggests competing interests need to be viewed against the different levels of my model. The model suggests that developmental moves that genuinely encourage more inclusive cross-disciplinary learning are to be encouraged, and the aim for sustainability to be key to critical maker-learning across diverse disciplinary perspectives should be central to planning. In the case study Hazel thought something similar to 'Subject Librarians' could be established to support the library makerspace. The case study university already has Subject Librarians in the traditional sense of looking after a range of subjects in order to be expert at supporting information literacy and resource needs in each area. However, it is difficult to imagine how something similar could be created for makerspaces. As Chris pointed out, it does not make sense to put a member of staff on a particular set of technologies in a discipline-specific manner as the situation changes all the time, across cohorts and within disciplines, as to which technologies might be of interest and how they might be used. With this in mind, it would make more sense to make Subject Librarians more aware of maker technologies and learning affordances within their disciplinary areas as an evolving field of knowledge. This does not imply that technical competency in the new technologies would be necessary, although better awareness would be. The Subject Librarians could then expand the professional possibilities of their role with established and new contacts. Chris also saw opportunities for Subject Librarians to develop their information literacy teaching to incorporate maker-learning. Work would need to be done to reframe it in the makerspace context. Still, as discussed in the preceding CHAT analysis chapter, Chris believed it was possible to employ Academic Librarians' domain expertise in a maker-context, perhaps by using the ACRL Framework for Information Literacy to outline key information-literacy concepts to students.

Hazel mentioned other ideas for expanding the service including introducing an artist in residence and connecting to an 'Immersive Scholar' programme at the university: 'You could do that with a makerspace, have a fellowship, bring people in, with expertise, have them run a few workshops, have them produce exemplary materials' (AC/HUM/1). She mentioned more things that could be done in the makerspace, including book-binding, and interestingly given the agricultural origins and focus of this university: ‘If it was me I would hook up the makerspace with the ice cream parlour down here and start doing interesting things with ice cream and food printers. I mean we're an agricultural school, you could do amazing things with makerspaces and agricultural technologies', a definite contradiction to existing ideas of what constitutes general maker culture but one that prompts interesting developmental ideas as I shall go on to discuss.

9.3.3 Support for Digital Humanities, Art/ Design and Science

There is some tension reflected in the case study makerspace between the overall mission of this university as an agriculture and STEM-focused institution and the Digital Humanities activities I found in this research. This reflects wider tension in HE between STEM/ engineering needs and humanities and the arts:

> Courses in the humanities, in particular, often seem impractical, but they are vital because they stretch your imagination and challenge your mind to become more responsive, more critical, bigger. (Nussbaum, 2009, *np.*)

However, this tension can be invited into a makerspace as a kind of ongoing productive dynamic as I have shown in my model and is perhaps what makes makerspaces such innovative learning spaces for fostering interdisciplinarity. It was interesting to see Digital Humanities becoming more accepted in anumber of ways here. Firstly, Humanities-based maker-learning contributes to broader strategic aims of providing opportunities for improving students' digital capabilities on all courses. Secondly, although students at this university are unlikely to major in English, it is still an important cross-faculty subject, with rhetoric and communication deemed important to all HE learners. Peter also outlined the importance of the university's strategic interest in 'innovation' for promoting Digital Humanities, which have 'a fighting chance because the university prioritises innovation' (AC/HUM/3).

Further development of Digital Humanities and Critical Making seems likely with new courses emerging such as 'Digital Research and Scholarship'. Peter also mentioned a new course he would teach in the spring called 'An Introduction to Digital Humanities'. Adrian highlighted his vision of growing the Communication, Rhetoric and Digital Media (CRDM) programme in relation to the library makerspace service. This programme builds on relationships with industry and academic departments to provide internships, summer jobs and applied research projects.

> It would be great to have grad assistants from lots of different disciplines that could embed in the space and serve as a two-way communication with their disciplines. They could outreach to their disciplines but also bring in expertise from their disciplines to the space. (Adrian/ PRO/LIB/1)

Welcoming more arts and humanities subjects would require proactive thought about what tools are available and how they are promoted. Although, as I outlined earlier, it would be difficult to have Subject Librarians as such for the emerging technologies in the makerspace, given the multiple uses for the same technologies across different disciplines, Hazel did make a good point about how some technologies are currently neglected and put away: 'Sometimes you get machines in there like the embroidery machines, and I've tried a couple of times to ask 'can you teach me how to use this', and there'll be like one person who'll be like ‘I think I can figure out how to use that and maybe I can show you'. She also cited Ann Shivers-McNair's research (2019), that showed how makerspaces where technologies are not fixed, may find technologies and furniture migrating to each other in logical use patterns:

> I think you need the space to cluster them, you need the space to be able to move the objects from one place to another, and if you lock them down they are always going to stay in that space even if it's inconvenient for the actual users. (Hazel/AC/HUM/1)

This kind of move to allow the makerspace users more freedom to define how they want to arrange the technologies and furniture in the space is definitely at odds with what is currently possible in the academic library makerspaces in this case study, primarily due to space limitations.

Another way of combating space limitations and reaching out to a more diverse range of students beyond STEM would be through more outreach work. Science teachers Charlotte and Miranda, while seeing the potential value in expanding the library's physical makerspace and services, made suggestions pointing to different ways this library service could evolve, providing an interesting contradiction to the static-site makerspace service where more tech and services could be taken to where the students are: ‘The library is not a building. It is more like a community’. (Charlotte/ AC/STEM/1)

9.3.4 Expanding inclusivity and diversity outreach

Although much work has been done, the high proportion of male STEM students using the space showed an ongoing challenge to more inclusivity. The 'Making Space' programme with its events and activities to bring marginalised voices into maker culture was commendable. Picking up on Charlotte and Miranda's idea of the library as being not so much a space as a potentially university-wide community, these events could be held in different parts of the campus with outreach maker activities being carried out afterwards, and equipment hired at that point. Part of this outreach could be aimed at the non-STEM audience with the most accessible tech available (e.g., Arduino, Raspberry Pi). Opportunities to further engage and develop relational norms with students could then be carried out when items are returned to the makerspace. This is a model that could potentially work at other academic library makerspace services.

9.3.5 Further developing maker-learning

A new kind of more emancipatory common knowledge around critical maker-learning could involve gentler types of activism around social justice issues and the makerspace becoming a hub for innovative thinking around sustainability issues in particular. To meet ethical challenges to sustainability in new localised environments, academic library makerspaces could also have as a key part of their mission a focus on developing usable technologies to help local communities. For example, during the current viral pandemic (Covid 19) makers, including at the university library service of this case study, along with others globally, produced 3D-printed protective face masks and other medical equipment for local hospitals (for examples see blog from Choksi, 2020, the 'Covid Maker Response Website' and 'NIH 3D Print Exchange: Covid 19 Supply Chain Response'). Having become aware of this also happening in the UK, my own service lent our 3D printer and donated some filament to a similar local scheme to help the medical profession at a time of scarcity in protective clothing. The idea of developing a version of the Make-a-Thon as a more permanent local-solutions-focused concept could be combined with Peter's emphasis on the value of the idea of visiting scholars (e.g., with ethical entrepreneurial, artistic or industry-based foci) and Hazel's enthusiasm for an immersive scholar programme, where the makerspace would become a focal point for the development of new ideas of potential local and national benefit. Scholars could be invited to work longer term on socio-critical and sustainable maker projects, where critical awareness is combined with practical action, thus providing a cross-disciplinary research and project-based focused academic maker-learning community. Thus, an ambitious vision for maker-learning within HE could include more opportunities for critical makers to work with scientists, engineers and designers on real-world ethical projects such as creating useful medical tools and devices, or technologies to help monitor home energy consumption. The kind of projects focused on will depend significantly on the strategic aims of particular universities (so for example in the case study university inclusivity is a library service strategic aim, in terms of engaging BAME and LGBTQ students in maker activities, being addressed through the Making Space programme of events and activities).

There may be a specific opportunity at the case study HEI to expand on current projects concerned with sustainability by engaging with the agricultural focus of the university (as suggested by Hazel). 3D printing for food is now a growing phenomenon; for example, the Tinker Kitchen makerspace in San Francisco for food startups (Tinker Kitchin, 2020). If food making could be combined within the accessible DIY frame of the library makerspace with themes of sustainability, interesting cross-disciplinary ethical entrepreneurship projects that respond to ecocriticism and social justice concerns could ensue. New ideas such as this could allow a more vital and potentially transformative two-way dialogue with the maker movement. While broader maker-learning could still take place, the push would be to introduce specialist makerspace projects introducing new technologies that could enable more sustainable agriculture, along with a new version of the Make-A-Thon concerned with sustainable farming. This focus could link to STEM problem-solving aims as well as more critical and humanistic concerns about sustainability and inclusivity. A new Agri-Maker learning programme could connect to broader, more inclusive, ideas of what 'maker' knowledge could be.

9.3.6 The challenge and opportunity of cross-disciplinarity

The makerspace service is cross-disciplinary in having a wide variety of disciplines using the space. Students sometimes communicate with each other across faculty boundaries about the possibilities from different technologies. As mentioned, the Make-a-Thon, started in 2016 by Adrian with the Engineering Village, the Sustainability Office and Autodesk (a private company), was particularly commendable with its cross-faculty student groups working on sustainability problems and solutions. Although there is no evidence of a large scale 'real world' adoption of ideas or products, there is still arguably a strong educational value in this event. However, there was no clear evidence beyond this once-a-year event, of longer-term, genuinely cross-disciplinary projects and opportunities. The best idea I heard from participants (introduced in 2.3 above) about resolving this service aim and delivery contradiction was from Adrian in our final interview when he suggested Mariana's role could be mirrored for other Faculty areas (if the budget was available), so the relational agency and expertise of the Graduate Extension role itself could be a conduit for cross-faculty dialogue, creative new maker-related projects, and new ways to support students learning from all courses by challenging them with different learning perspectives. This idea is also potentially of interest to other academic library makerspaces.

9.4 Reflections on my model

The kind of critical and haptic engagement with material culture I have looked at in this thesis evolving between Critical Making and Digital Humanities could, as I have shown, be developed further through my cross-disciplinary learning model of Critical Material Awareness. I realise in positioning more ambitious, moral and emancipatory possibilities for academic library makerspaces as a part of a push to a more caring material culture; I am in danger of being accused of 'idealism'. However, to be entirely non-idealist and value-free carries no sense of direction, as it entails having literally 'no idea' what you are trying to achieve. I would argue we need to aim for a positive vision of an imagined future, or our actions are more likely to be culturally reproductive of the present (unless we deliberately intend to defend the status quo). As the developmental psychologist Anna Stetsenko argues:

> It is impossible to imagine a future unless we have located ourselves in the present and its history; however, the reverse is also true in that we cannot locate ourselves in the present and its history unless we imagine the future and commit to creating it. (2015, p.110)

Thus, for academic librarian not to engage with critical thought on the culture and ideologies inherent in their profession's scaffolding of learning and how they would like to see it evolve, and only focus on 'practical' service driven matters, is to potentially un-critically reproduce harmful modes of being: 'The hegemony of practicality within librarianship acts to reproduce patriarchy, neoliberal ideology, neutrality, and white supremacy'(Nicholson and Seale, 2018, p. 5).

9.5 Summary of Chapter 9

This chapter initially introduced my model for building HE-based cross-disciplinary maker-learning opportunities to empower students through activities that combine my concept of Critical Material Awareness with Critical Making and Design Thinking. The model is outlined in detail from the central figure of HE students (regardless of gender, background and subject studied), then the mediating tools and teaching available in the makerspace and the scaffolded training available including digital, media and information literacies. Surrounding this in the model is a layer showing ways of supporting students established from professional service staff's relational agency and common knowledge (Edwards, 2017) built with academics and student makerspace helpers, coalescing on the need to promote maker-learning through encouraging ethical, haptic, reflective activities. These critical maker-learning activities can build a new system and sites of intersecting practice across disciplines around interests beyond the purely technical towards authentic learning focused on real-world interests and goals (the final layer). I then apply the key knowledge from this thesis and my model to the case study makerspace and develop it as a theoretical exemplar for this and other makerspace services to consider, completing the CHAT-based dialectics of this thesis. My case study has thus built new critical maker-learning theory from analysing the problem space of tensions and contradictions found in multiple maker-learning disciplinary and cross-disciplinary activities, to present a new dialectical vision. Thus, this new case study sociocritical synthesis embraces the agricultural focus of the university by making sustainable food production projects a crucial part of the critical maker-learning available.

Chapter 10: Discussion and conclusion

10.1 Introduction

This thesis has looked at a US-based academic library makerspace through my perspective as a UK-based Academic Librarian. This final chapter will look in section 1 at the contributions to knowledge this thesis has made, and in section 2 at the wider insights and potential implication of these findings.

10.2 Thesis contributions to knowledge

The case study makerspace provided an opportunity to look at the pragmatics of organisational change through a cultural-historical framework in building a cross-disciplinary makerspace service. I have analysed the historical process of organisational change for this academic library service as it has moved beyond initial tensions through academic engagement across faculties. This led to learning experiences where the ZPD emerges in an interesting cross-disciplinary activity space involving spontaneous student interactions and peer-to-peer learning. Inclusivity and diversity were identified as key themes, with contradictions between different courses' (and therefore different student backgrounds including gender, race and status) use of the space analysed through qualitative and observational data from different learners including engineers and business students creating prototypes, science students creating molecular models, humanities students doing projects of cultural-historical exploration, and textile students exploring material-technical design affordances. The current lack of variety of technologies easily available (e.g., the embroidery machine of interest to critical humanistic perspectives was placed in a cupboard) is identified as a factor in currently restricting inclusivity and diversity aims at the case study site. The haptic engagement with the technologies in an exploratory manner was key to the learning I observed so the importance of the technologies being hands on was paramount. Thus, I also contribute to building maker-learning theory through my identification of the importance of the embodied nature of much maker-learning, a key finding from my research. I expand on my thoughts around this topic later in this chapter and outline some areas for further research.

The evolving role of academic librarians in the makerspace was a key finding from my research, with a more expansive role as educators becoming apparent. This case study demonstrated how librarians could develop new skills as interpreters of different disciplinary perspectives in the context of the makerspace and its tools. Relational agency and expertise developing common knowledge (Edwards, 2017) with academics, student helpers and other professional staff was shown to be vital to developing new learning opportunities. Edwards' relational concepts have yet to be applied to academic librarianship. This thesis has productively engaged with Edwards' theorising as a useful way of understanding modern academic library praxis, and of looking at how the role of academic librarian can build on relational strengths and values inherent in the profession to become a key educational role in supporting emerging twenty-first-century cross-disciplinary learning services. I have also looked at how critical information literacy pedagogies could tie in with Critical Making (Ratto, 2014), Digital Humanities and the open/inclusive nature of modern academic libraries to form a new critical maker-learning pedagogy, to join other emerging cross-disciplinary learning models.

CHAT (Engeström, 1987) based dialectical analysis has led me to argue for the case study makerspace service to act as an exemplar for other similar services to build from the tensions and contradictions found in the present situation between STEM-focused maker-learning and more critical humanities-based use of makerspace. This case study provided a complex problem space around maker activities with variable participant awareness of and interest in maker culture; critical views of the maker movement from Digital Humanities and Critical Making perspectives; and contradictions between the needs of STEM, STEAM, entrepreneurial, and humanistic educational use of the space. Also, there is a lack of productive academic library makerspace-based community interaction with local business or civic and government interests which could aim for inclusivity and sustainability projects that tie in with regional needs. Thus, I go on to propose a vision for HE-based makerspaces based on tapping into the key strategic aims of the university to make a potential real-world impact. For the case study makerspace this could mean making sustainable food production projects a key focus of specialisation for the maker-learning available, fitting in with the agricultural focus of the university while also attracting scientific, humanistic and business interests. Key practical suggestions from this thesis also include my theoretical expansion of the commendable sustainability-focused 'Make-a-Thon' concept, and the inclusivity and diversity-focused 'Making Space' programme, ideas that could work well at other universities.

As well as practical suggestions for creating inclusive, sustainable, cross-disciplinary HE library-based makerspaces I have also contributed to maker-learning theory through my higher education concept of Critical Material Awareness and my related model for building HE-based, cross-disciplinary, socio-critical maker-learning opportunities that aim to empower students. A move to make Critical Material Awareness an integral part of *all* learning systems and pedagogies in HE as I propose could open a new transferable conceptual gateway for meeting cross-disciplinary sustainability and inclusivity educational aims helping to fulfil HEIs ‘essential role in sustainability’ as a ‘key agent in the education of future leaders that will contribute to the successful United Nations Sustainable Developments Goals (SDGs) implementation’ (Zaleniene & Pereira, 2021, p.99). Nor can the strategic policy aim of HEIs to meet SDG targets be separated from the issues of inclusivity and diversity I have discussed in this theses, as it is the poorest and most marginalised communities that will be potentially irreparably damaged by climate change. Critical Material Awareness, as a learning system that promote sustainable development through inclusive entrepreneurial projects encourages learning that incorporates the interrelated themes of ‘environmental integrity, economic vitality and a just society, for present and future generations, while respecting cultural diversity’ (UNESCO, 2018). Thus Critical Material Awareness is potentially a part of a new cross-disciplinary movement of learning systems looking to potentially harmonise environmental and economic concerns in the common knowledge of the urgent action required to move beyond the futile, intransigent stand-off between reactionary neoliberal politics and progressive movements.

Lastly, the research paradigm I have introduced can be considered a contribution to knowledge in that my philosophical position on epistemology and ontology, what I have termed 'Socio-Critical Realism', combines sociocultural perspectives, embodied learning science, and critical pedagogy (including critical information literacy) in a middle position to challenge the still prevalent social science paradigms of positivist fueled scientism, and post-modern relativism. My Socio-Critical Realism aims at a balance between the material reality that science uncovers, which proves such facts as climate change are real, and the undoubtedly primarily cultural lives we lead:

> If it is extremely dangerous to say that reason is the enemy that should be eliminated, it is just as dangerous to say any critical questioning of this rationality risks sending us into irrationality … it was on the basis of the flamboyant rationality of social Darwinism that racism was formulated. (Foucault, 1994, p.358)

I will now go on to reflect on these key aspects of this case study before drawing my conclusion for this thesis.

10.2.1 Further reflections and implications from this research

I adopted the CHAT framework for this case study as an analytical rather than interventionist tool. This approach, at first, may not seem to engage with the full transformative opportunities from this theory if choosing to work with research participants in a directly interventionist manner. However, as an analytic tool looking at the evolution of a specific successful academic library makerspace service (in terms of visitors, reach and range of services), CHAT's radical localism and focus on systemic tensions/contradictions beyond the empirically obvious, has been very useful in thinking through what 'success' in this context can mean for the future of this makerspace service as well as services in different contexts.The triangular models' CHAT encourages were undoubtedly useful. However, they were certainly nuanced by drawing on Edwards' relational concepts, and I found the diagrams limiting when thinking about the ontology of learning across disciplines in this case study makerspace (hence the use of a table instead).

Drawing on Template Analysis to link themes with the CHAT framework was helpful, as it allowed for *a priori* understanding from my previous makerspace research, as well as enabling the framework to inform my emerging analysis from the start (although entirely open to challenge from the data as shown from the much further developed final template analysis shown in Appendix 5). Dervin's Sense-Making Methodology (2003) was useful in emphasising how so many information needs were met in this makerspace in the ZPD between students, and from the dialogic scaffolding of helpful information and advice from professional and paraprofessional staff support, as well as through fast-changing open-source online resources.

My research has revealed tensions between the recognised need for inclusivity and the factors that prevent its realisation, including the large variety of pedagogies, prototyping and participatory learning models in maker-learning. Many universities are looking to deal with the issue of inclusivity in ambitious strategic plans (as is the case at my university). Although ambitious statements are always relatively easy to make, the question remains, at a time of squeezed budgets and questioning practices, how seriously are universities tackling the challenge of increasing inclusivity and the related need for cross-disciplinarity? As mentioned above this question is particularly pertinent while universities try to meet the needs of a new generation facing global issues such as increased nationalism and a lack of globally coordinated *action* on climate change. I will explore these issues further now in the context of learning from this library makerspace service, as well as drawing broader reflections from my practice.

10.2.2 Academic librarians' relational agency and technological expertise

Initial practical concerns (e.g., space design, furniture choice, technology security) were a challenge for this makerspace service as were financial challenges. The use of the Relational Concepts (Edwards, 2017) was key to my understanding how this service developed primarily through 'relational expertise' (a concept I feel sure many academic librarians and other university support staff such as learning technologists will have some affinity with). It was apparent that Adrian and Daniel were the key initial drivers in the creation and development of this makerspace programme, and it was their enthusiasm and drive that has attracted senior management interest and the budget required for the staff and student workers who have made this makerspace successful. Adrian and Daniel's aim of focusing the service on meaningful learning, as established in liaison with academics, is now being developed and expanded further through Chris and Mariana's interest in developing new academic learning activities in the space. The danger is that without this kind of vision, drive and relational agency their goals would not 'become included in practices that support the well-being of others and ultimately of themselves' (Edwards and Mckenzie, 2008, p.168).

Attempts to develop academic library makerspaces at many HEIs could just result in a kind of petting zoo for technologies without in-depth engagement and innovation occurring. The academics I interviewed from the humanities and sciences, all praised what can be considered the 'common knowledge' (Edwards, 2017) that could be established with the librarians supporting the space, with the makerspace staff providing an interpretive conduit between academic concepts, learning aims and the possibilities of particular technologies. Edwards' relational concepts have acted as a useful tool for increased understanding in the cultural-historical and sociocultural analysis as I have employed them. It is also worth considering their value to any profession that has or should have, care and attention at its heart. We need to have a professional growth mindset to develop common knowledge as a kind of developing virtue ethics between professional groups such as librarians, learning technologists and IT. As well as establishing overlapping professional norms, we can then imagine and experiment with new shared services within expanded horizons. This offers

> an additional form of expertise which makes it possible to work with others to expand understandings of the work problem as an object of joint activity, and the ability to attune one's responses to the enhanced interpretation to those being made by other professionals. (Edwards, 2010, p.13)

Recent studies in LIS have emphasised the need to expand our educational interests and become more connected to social justice projects (Corrall and Jolly, 2020). However, how we enact and understand our relational activities as academic librarians is currently under-theorised, and I hope to have shown that Edwards' concepts can improve understanding of many aspects of academic librarians' work. In moving to support new technology-enabled learning spaces and models, we will need to work closely with IT and learning technologists, as well as academics. The common knowledge we can bring from our professional perspective and values is shown through participants in this case study, demonstrating their service ethos and dedication to open, inclusive learning. In addition, academic librarians' interpretive skills (as identified by Hazel and Maddie) can help to bridge fast-emerging information gaps, while helping to align new library maker services to academic subject needs and course projects. These relational and interpretive skills are perhaps just as crucial to scaffolding the maker-learning process as technical know-how and are integral to what can make an academic library makerspace service a genuinely inclusive, cross-disciplinary learning space as I have argued in this thesis.

However, it is worth noting again the three key professional librarians (Adrian, Chris and Daniel) who are driving the advances of maker-learning at the case study site are technically knowledgeable as well as relationally astute. In my own professional practice the key to the success of our Technology Engagement Group which experiments with new technologies and introduces them to the university where we find an internal academic partner wishing to explore new learning opportunities (e.g., student and staff projects utilising 3D printing, scanning and photogrammetry with our Anthropology and Arts schools) is highly dependent on the technical expertise on one of our librarians. This suggests as well teaching critical information literacy and cross disciplinary relational awareness and skills, library schools need to have optional modules available for students to who want to take their technological skills beyond basic IT and digital literacy to explore more haptic and embodied learning with emerging technologies. For those who don’t want to specialise in critical maker learning, there still needs to be an awareness of this built into all library school degrees as well as an interest in other emerging library-based and related technology-enabled learning phenomenon. This research also implies there is a need for Critical Material Awareness amongst librarians such that digital literacy is linked to its material/ecological implications, potentially creating another opportunity for increasing librarians expertise and teaching (thus academic librarians could look in the future to teach information, digital *and* technological/ material literacy as all these concepts have strong inferential sociocritical connections).

10.2.3 Maker-learning gains

It was clear from research participants that makerspace-related work was being evaluated in different ways across different disciplines. For example, Maddie described how she adjusted her marking of the material component of maker-related projects (an activity involving the creation of symbolic objects related to real people to then be described in written text) to emphasise text-based description for English students, and aesthetic value for Arts. Charlotte and Miranda described a very different learning process with science students where the aim was 'exploration to construct, deepen, refine, or integrate understanding of relevant disciplinary content'. Students designed puzzles using the library makerspace to show how micro-biological systems worked and took them back to the classroom for guided reflection and discussion. They were assessed on the scientific accuracy of the object in showing how the biological system operates.

The future of academic library makerspaces is a still-evolving area of research interest. Wilczynski, Wigner, Lande and Jordan (2018) looked at the high value of academic makerspaces for 'accreditation and beyond', emphasising the value of one open to the entire university to illustrate 'the concept of continuous improvement as a mechanism to improve learning and promote creativity' (p.3). They go on to argue that if observational, qualitative and quantitative data can be gathered as evidence, a number of accreditation relevant factors could be supported including self-efficacy for lifelong learning, effective communication skills, a better understanding of STEM concepts as well as 'design thinking, project-based learning, independent exploration, collaborative problem solving and entrepreneurial endeavour' (p.4). Thus, HE-based makerspaces could form part of a new design movement for new learning environments that meet the long-held goals of research in the learning sciences as summarised by Packer and Maddox (2016, p.140): 'There has been a remarkable degree of consensus among learning scientists about what good learning consists of: it should be "practical", it should be "relevant", and it should be "dialogical"'.

However, the proposed measurements of maker-learning in the literature so far may omit some of the key critical values of maker-learning I have argued for in this thesis. In measuring learning outcomes of any kind, there are philosophical questions to be asked first. These are concerned with what you are trying to measure, which at the core must align with a view of what the purpose of higher education should be. Disciplinary conventions often attempt to answer this need for purpose with, for example, the humanistic concerns of the arts or the market focused concerns of Business. Is higher education for developing knowledge workers for the economy, providing opportunities for social mobility, or for giving a greater understanding of self and society? Thus, learning goals could include broader social aims such as those I have highlighted about sustainability and inclusivity, goals that are hard to measure. There are also wider questions that this (and other) makerspace-based research asks. Is it possible that creative activities carried out alongside traditional degree courses, may be just as crucial to future life aims as those within the degree (in terms of building self and group efficacy, independence, maturity and responsibility)?

10.2.4 Information science and maker-learning

The information literacy support examined in this case study was mainly face to face. It involved dialogic reasoning around information needs in a joint interpretive process with the learner and a more capable other (student or staff) in the ZPD, where commitments to current understandings needed to be made explicit. For example, this was shown in the support Mariana gave her students by using their shared understanding. Thus sense making gaps were bridged through awareness of interrelated concepts within expanding learning horizons that became integral to the learner's agency and ability to go on developing 'higher-order' thinking. This illustrates Vygotsky's sense of building socially constructed then internalised thought and language involving a complex, expanding interplay of increasingly clearly defined concepts tested through empirical observation (as in the makerspace) and later reflective reasoning. As information scientist Birger Hjørland observes:

> Information seeking … should be viewed as a link in the cooperative process of knowledge production and knowledge utilisation. Scientific concepts are not arbitrary but necessary. If they are incorrectly defined, they bring about theoretical blockage and implications which can be falsified either empirically or logically. (1997, p.11

Thus, logic and reasoning can be employed effectively in academic library support through interpretive, critical questions designed to understand people's beliefs framing their information needs. This is a process of asking normative questions about people's commitments as they change over time, an essentially Socratic process that Brandom (1994, p. 141) describes as 'deontic scorekeeping'. The 'Critical Making' process looked at in this case study is a good example of reason-based critical thought that effectively brings out the cultural baggage around particular technologies though a kind of logical-cultural deconstruction. As the post-phenomenological philosopher of technology Don Ihde has observed, technologies have politics and cultures: 'I am used as much as I use any technology' 1993, p. 117). Thus, the essential critical question of *why* engage with a particular new technology must always be asked, while we consider the ongoing worth of existing technologies.

10.2.5 Embodied/haptic maker-learning

Adding to the importance of critical, dialogic reasoning and information literacy, I have argued in this thesis for the equal importance of the embodied and haptic element of the learning process. These two key areas of learning theory, the social and the embodied, can be reasonably connected through the realisation that the haptic reinforces the rational and vice-versa. The haptic can sometimes lead the rational in initiating and grounding embodied understanding with the naming/conceptual process of language, and to speech that can be seen to 'accomplish thought' (Merleau-Ponty, 1962, p.183) when moving beyond the limitations of 'private language' (Wittgenstein, 2009, p. 95) to Brandom's shared normative sociocultural meaning (fulfilling our ethical duty and need to understand each other as human beings). Thus, as demonstrated in the maker-learning processes shown in the projects I observed in the makerspace that are personally meaningful, whether imaginative as with the symbolic representation of the work of immigrant forbears by the Latino student I observed, or practical as with a carabiner made by Rachel's project group or her own fixing of her iPhone charger, what *matters* to humanity is key to learning, and is defined as much by our practical, embodied intuition as our general cultural awareness.

> Virtually all objects are cognitively innocent, or epistemologically non-existent, until an agent relates to them …They have to matter for the agent in some way if they are to be discovered as affordances. (Radman, 2013, p. 372)

In my practice I still find a physical copy of a scholarly journal helpful to pass round to students so they can hold and explore it, while I explain what a journal conceptually *is* (not something all undergraduates are familiar with when they start their studies), and how a journal article differs to a magazine article (e.g., the importance of peer review, format including research design, methodology, data, analysis etc.). Although most journal searching is done these days electronically, this haptic, as well as explanatory, learning process helps to embed the concept of the 'journal article' as part of the research and learning process in the students' minds.

10.3 Defining 'success' in an academic library makerspace service

It is now informative, having reflected on insights from the paradigm and research design, to look more at the findings in relation to how the core question of this thesis has been answered: How can an academic library makerspace develop as an inclusive cross-disciplinary learning space and service within a Higher Education Institution? The CHAT analysis brought out tensions in what constitutes ‘success’ regarding this aim in a broader cultural-historical sense with regards to this makerspace service. It became clear although success could be measured by the (high) number of workshops, technology-based learning affordances and course-related teaching carried out, the greater success for this academic library makerspace service was more concerned with the particular value it can embody in terms of being a genuinely open, *inclusive*, *cross-disciplinary* space for learning that is tuned-in to technologies that would not just appeal to STEM students, and would also try and address *sustainability* issues (particularly in the sense of environmental concerns). Success across these aims such as I have shown has primarily been achieved through the relational expertise of key staff who were well supported from a senior level in their ambitions.

A central contradiction that emerged in the research between the case study makerspace culture and the wider maker movement could be seen in the fact that the majority of participants were either critical of or ambivalent about wider maker culture. With Digital Humanities and Critical Making projects emerging, maker culture can seem a cultural *zeitgeist* that has created interesting epiphenomena when critiqued from humanist and post-humanist perspectives. The question of whether, if an academic library makerspace is of interest within an HEI, to call it a 'makerspace' or something more contextual and specific, remains difficult. I think that to move away from the 'maker movement' entirely at this stage could be counter-productive to the potential educational value of the new service. It would seem for now that Digital Humanities and Critical Making are evolving in a dialectical movement at least partly within broader maker culture. This new educational horizon was observed most strongly in the views and pedagogical approaches of Hazel and Peter, involving creative but also critical uses of the makerspace and 'maker' activities (e.g., the 'intimate fields' project, and the 'steampunk' use of junk objects from The Scrap Exchange). Without the makerspace as a focus, these dialectics between engineering and what Peter calls 'anti-engineering' may not play out in quite such interesting ways, thus providing a broad palette of what ‘authentic’ learning can mean from different disciplinary perspectives incorporating critical and moral viewpoints.

10.4 Further Research

This CHAT-based case study has helped to demonstrate how the mix of learning paradigms found in makerspaces demonstrates the potential permeability of existing knowledge boundaries in the mediated action of the low and mid-level of maker-related knowledge construction (rather than more highly theorised research in quantitative data-focused disciplines). However, the practical, creative skills being fostered in a makerspace may turn out to be as useful as much apparently 'higher-level' learning. As the neuroscientist Daniel J. Levitin observes:

> Students who graduate from top universities in technical or quantitative fields …know how to apply what they've learned, and know-how to look for information they need. But relatively few can effectively think and reason for themselves. (2014, p.356)

The lack of much in-depth established antecedent knowledge at an undergraduate level may help cross-boundary, creative possibilities to develop maker-learning expansively at an early stage in a learner's life journey (as with the Zen maxim: 'In the beginner's mind there are many possibilities, but in the expert's there are few', Suzuki, 2011). An attentive openness to new possibilities is an essential ingredient in the embodied, creative learning process before the rational mind takes over to complete particular aims, as educational psychologist Guy Claxton (1997, p. 131) suggests: 'broad, diffuse attention is precisely what is needed in non-routine… situations, where data is patchy, conventional solutions don't work, and incidental details may make all the difference'. However, scaffolding from more knowledgeable others is also required (as with the academic, staff and student maker support in this case study) to progress skillfully and create what cultural writer Matthew Crawford positions as a 'dialectic between tradition and innovation' (2015, p.243). Thus, established creative paths can be taken further (as nothing is created completely *ex nihil*) as new tools in the makerspace become more familiar, their use thus becomes more apparent, and new projects are begun.

The openness of the academics I spoke with to challenge pedagogical norms from their field, also shows how it is possible, even for those with more knowledge, to be amenable to re-evaluating their assumptions around teaching practice. Charlotte and Miranda**,** for example, were interested in expanding their idea for a website to share and remix STEM-maker pedagogies and activities to a STEAM-based resource. This maker culture inspired open-learning ethos offers intriguing possibilities for higher education, as students coached in this open learning approach might be more amenable to genuine cross-disciplinary work as they achieve higher levels of learning and knowledge. Learning in this open model also contains the possibility of transformation for teachers and well as students and includes an element of challenge and risk: 'Study is transformational; it is not training. Far from offering protection and security, or making things easy, study can be difficult and disturbing: it breaks down the defences of preconception and unsettles thought' (Ingold, 2018, p.15).

From my research in this case study, particularly with Critical Making and Digital Humanities activities, I can suggest two elements of maker-learning practice where further empirical research and resulting educational and pedagogical understanding could be developed to meet the need for a higher level of maker-learning theory. This move would look to build understanding in two key areas:

1) **The importance of dialogic and embodied learning for *all* disciplines:**

Embodied learning can be useful for cognitive development through practical, materially based learning activities in more 'academic' as well as vocational subjects. I have tried to navigate a middle path in this thesis between the 'mind in society' vision of Vygotskian thought and learning that is practical and dialogical, and more recent theories concerning the embodied nature of mind (e.g., Andy Clark, 2016). It appears the sociocultural domain of theory is yet to engage with the more cognitive-focused embodied learning models in any depth, but this is a bridge that can be crossed if the 'embodied' model resists the kind of determinism that negates the individual and collective agency achieved through rational, dialogic, culturally situated human activity. The sociocultural and cultural-historical perspective requires a better understanding of the fully embodied nature of 'thinking', perhaps especially the realisation that we need our bodies for all levels of learning, including 'higher'. Emerging research summarised by Shapiro and Stolz (2019) suggests that understanding embodied cognition and education will involve more research on how firsthand embodied learning (which is reinforced by secondhand descriptive language-based learning) manifests itself in gestures that may indicate progress or stasis, and in actions that simplify cognitive load during complex tasks and may help to encode concepts through bodily movement (Shapiro and Stolz, p.33). I have argued in this thesis that our hands have particular importance to maker-learning, with the haptic reinforcing cognitive awareness through complex, purposeful material interaction that reinforces the importance of the object to the learner's reality, whether a direct relationship with the material object or with a representation (as with scientific models and puzzles) of an object too large or small to handle. 'Sometimes we think with our hands' (Menary, 2013, p. 357) and our learning environments, as in maker-learning, could do well to take this on board across all disciplines:

> Our developmentally plastic brains exhibit learning plasticity when they are coupled to a highly scaffolded learning environment; the brain is profoundly transformed, and consequently, we are cognitively transformed in a deeply profound way. The hand is … complicit in the transformation. (Menary, 2013, p.357).

Embodied, haptic learning can be seen in this case study with engineering students making prototypes, entrepreneurs making useful handheld devices (e.g., Rachel's karabiner), science students realising the value of manipulating 3D puzzles with your hands for molecular understanding, textile students exploring the potentials of different materials with new technologies through handling and experimenting, and humanities students expanding their awareness of cultural objects through historical recreation or physically combining the old with the new to explore new cultural insights and possibilities.

2) **The importance of dialogic and embodied learning for critical pedagogic theory and praxis:**

Critical theory of all kinds can be enhanced through embodied material interactions with emerging and older technologies bringing to light (and life) supposedly familiar technologies we are often culturally alienated from. Thus, through a critical and creative investigation, more in-depth understanding as to what the technologies' revealed meaning is to humanity can be achieved. As Heidegger warned, 'in our sheer preoccupation with technology, we do not yet experience the essential unfolding of technology' (1978, p. 238). This educational move will involve expanding and connecting critical material understanding into a more culturally and ecologically aware, rather than a market-led, idea of the real-world 'impact' from higher education research. This could be achieved through educators across all disciplines incorporating key course learning elements to challenge the current reality that citizens are mostly passive consumers of products and technologies, through curricular and extra-curricular projects that have an impact at a local or national level (for example, a more ambitious version of the Make-a-thon from this study). Maker-learning can thus be a key educational tool to help students to become appropriators, creators, and repairers of practically useful or culturally insightful and enhancing technologies that benefit humanity. As Unger and Ikeda (2016, p. 53) remind us, 'when used as tools to promote the good of humanity and life… science and knowledge become an art'.

10.5 Conclusion

This case study has explored the tensions and contradictions around university-level, disciplinary and professional principles in the development of an academic library makerspace. I have used Cultural-Historical Activity Theory (Engeström, 1987) to identify these tensions. How they were overcome to various degrees will be of interest to less-developed academic library maker services. This ranges from practical matters of securing finance, budgets, space, equipment and staffing through key stakeholder engagement (senior management and different academic areas) to broader challenges around the makerspace's place within the historically established learning ecology of the university including different disciplinary perspectives, learning models and aims. The main broader cultural-historical themes that my CHAT analysis has revealed have been inclusivity, sustainability (including environmental concerns) and cross-disciplinarity. These three significant themes interrelate and will all need considerable professional focus for the future success of maker-learning within HE.

Thus, this case study-based argument is that a new cross-disciplinary system of critical maker-learning can aim to empower students to explore their own agency towards an awareness of and a responsibility towards making positive material changes in the work they do whether in public, private or non-government progressive organisation careers. As professional owners of the core inclusive cross-disciplinary learning spaces in HE library services are in a strong position to aim to meet the needs of all academic disciplines and students from all backgrounds. This will create ongoing challenges, tensions and opportunities in terms of priorities with the new cross-disciplinary creative learning opportunities that arise. In terms of key practical findings for academic library services, this case study suggests that a small number of dedicated staff with maker knowledge, enthusiasm and relational expertise (Edwards, 2017) are the key drivers as well as growing awareness from established HR library professions, particularly Academic/ Subject Librarians. In terms of the scientific nature of the learning taking place in this academic makerspace (and by reasonable inference others) this thesis has argued for the importance of the sociocultural *and* embodied and haptic nature of much maker-learning to be recognised and explored through makerspace research in the future. As I have emphasised, this research suggests our hands can reinforce and sometimes lead the learning process (Radman, 2013, p. 378).

Without the vision, enthusiasm, and dedication of academic librarians with their own interest in maker culture, the case study service would not have developed as it has. It is also apparent that the staff and students that have been drawn in to support the makerspace service are capable of similar levels of relational agency (Edwards, 2017), opening up further educational possibilities for the service. My own professional outlook has been challenged and transformed during this research through the realisation that academic librarians can and perhaps should enter more proactively into educational conversations as their cross-disciplinary perspective is of increasing value to a Higher Education (HE) world in need of connecting cross-disciplinary learning with real world issues. This new perspective of academic librarians as key HE cross-disciplinary educators has inspired me to present my maker-learning model for HE that aims to create learning spaces that promote inclusive, sustainable socio-critical awareness (employing my concept ofCritical Material Awareness) and empower students to build self and group-efficacy through authentic, problem-based learning. I have also shown in this thesis how the radical localism of CHAT based analysis can inspire expansive development across cultural boundaries and contexts, accepting that the opportunities opened up by a specific case study, such as the possible food production focus for this makerspace, may lead to radically different possibilities in other cultural contexts.

From an academic library development perspective, the most important finding was the specific value of library support that academics and students from this research saw as helping them with the interpretive process of looking for technical, digital and critical information in emerging areas of much uncertainty. Maker-learning in an academic library environment provides a chance for students and academics to step outside the stricter rules of strong pedagogical positions, and a relentless focus on course 'outcomes' that can become a tick box exercise. As Tim Ingold (2018, p. 35) has argued, a 'weaker' pedagogy can sometimes allow us to open up to more possibilities, as it disarms us from becoming too defensive in our apparent certainties: 'shut up in our armour … walled in by our intellectual defences, we fail to take in or respond to the reality the world presents to us'. However, an argument that attempts to deconstruct aspects of the sometimes constrictive and authoritarian power of excessive pedagogic certainty in HE may be problematic without critical meta-pedagogical models for more open cross-disciplinary learning, such as I have proposed in this thesis. I hope to have shown in this thesis the value of pockets of third space enabled and scaffolded creative freedom, such as critical maker-learning, that can help students to find their own path within their overall HE learner journey in a dialectics of expansive learning across and beyond curricula. I also hope to have shown the professional pragmatics required to achieve genuinely creative and inclusive cross-disciplinary learning with academics, professional staff, and students co-creating new learning opportunities through collaborative critical maker-learning activities. Through this expansive, creative cross-boundary learning design process, further innovative cross-disciplinary learning models may evolve.

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Appendices

Appendix 1 Abbreviations and maker-learning terms

AC – Academic

ACRL – Association of College & Research Libraries (US)

BERA – British Educational Research Organisation

CHAT – Cultural-Historical Activity Theory

CILIP – Chartered Institute of Library and Information Professionals (UK)

CoP – Communities of Practice

DARPA – Defense Advanced Research Projects Agency (US)

DIY – Do-It-Yourself

HEI – Higher Education Institution

HUM - Humanities

IFLA – International Federation of Library Associations

JISC – Joint Information Systems Committee (UK)

LIB - Qualified Librarian

LIS – Library and Information Science

MVP – Minimum Viable Product

PRO - Professional and Paraprofessional Staff

RFID – Radio-Frequency Identification

RSA - Royal Society of Arts (UK)

SCONUL – Society of College, National and University Libraries (UK)

STEM – Science, Technology, Engineering and Mathematics

STEAM – Science, Technology, Engineering, Art and Mathematics

STU - Student

ZPD – Zone of Proximal Development

Definitions of key maker-learning technology and terms

3D Printing: The process of digital fabrication involving making a physical object from a three-dimensional digital model, usually by laying down ('printing') many thin layers of a material in succession.

3D Scanning: Analysing a real-world object to collect data on its shape. The data can then be used to construct digital 3D models for art and design purposes and for 3D printing.

Adafruit: Company selling electronic products and learning resources related to electronics, technology and programming.

Arduino: An open-source electronics software platform and single-board microcontroller that can read inputs (e.g., a finger on a button) and turns them into outputs such as turning on an LED.

Augmented Reality (AR): A technology that superimposes computer-generated images on the user's view of the real world.

AutoCAD: A commercial Computer-Aided Design (CAD) and drafting software application. Use examples include artists and designers creating digital designs of 3D objects or spaces.

Celestron Handheld Microscope: Easy to use low powered microscope.

Circular Economy: Using resources as long as possible, extracting the maximum value, and recovering and regenerating products at the end of their service life.

CNC Machinery: Computer Numerical Control machining tools (e.g., for milling) used to process materials (e.g., metal, plastic or wood) to meet the specifications of a coded, programmed instruction.

Digital Embroidery: Converting a graphic into a stitch file that can be read by a sewing machine.

Internet of Things (IoT): The network of physical objects ('things') that are embedded in software, sensors and other technologies to exchange data with other systems over the internet (e.g., smart home appliances such as thermostats and security systems).

iRobot Create: Preassembled mobile robot platform, including LEDs and sensors, can be programmed for sounds and movements.

LED: A Light-Emitting Diode, an electronic device that emits light when an electrical current is passed through it.

Maker: Someone who creates and shares.

Makerspace: A place to design, create and share in a space encouraging learning by doing, and progressing through experimentation.

Makey Makey: An invention kit designed to explore circuitry to connect everyday objects to computer keys (e.g., aluminium foil, metal utensils).

Maker Movement: The growing community of makers, often centred around new technologies.

Makyu: Desktop vacuum former to make plastic moulds out of most things.

Moog Werkstatt-01: Compact analogue synthesizer kit.

Photogrammetry: Obtaining reliable information about physical objects and the environment through photographic images to create digital images or objects which can be used in 3D VR programmes.

Raspberry Pi: A credit-card sized computer that plugs into a monitor or TV and uses a standard keyboard, and the programming languages Scratch and Python.

SolidWorks: A solid modelling CAD program that runs primarily on Microsoft Windows, designed to operate within the constraints of the shape and purpose of solid models.

SparkFun: An electronics online retail store selling items to make electronics project possible.

Sphero: A white spherical robot capable of rolling around under the control of an i-phone or tablet.

Thingiverse: A website for sharing user-created digital design files.

Tinkercad: A free, online 3D modelling program that runs on a web browser.

Upcycling: Transforming waste materials and products into new, better quality, products.

Virtual Reality: A computer-generated simulation of the real world using electronic equipment, including a helmet with a screen inside and gloves fitted with sensors.

Wearable Technology: Electronic devices that can be worn as accessories or embedded in clothing.

Zine: An informal magazine (e.g., a fanzine).

Appendix 2 Interview schedules and data analysis examples

Online interview with case study university makerspace project manager (asynchronous 1week) and follow up interview on site.

1. What is your role at the university?
2. How did you get involved with the library makerspace project?
3. How does the makerspace relate to the others on campus in terms of purpose and who uses it?
4. Please can I confirm the main categories of equipment that the library makerspace hosts (e.g.Type A 3D printers (6), Fusion 360 and AutoCAD loaded on lab computers, Tools and models for 3D printing, Electronic kits and parts for short term loan)?
5. Please can I also check on the clubs that currently use the library makerspace, and the eventsthat are recurring (e.g. 3D Printing, Arduino Workshop).
6. Who are the professional and paraprofessional staff that support the makerspace?
7. What teaching/ training do library staff offer to support makerspace activities (e.g.information, digital, technical, critical literacies)?
8. Are academic librarians at your university tenured?
9. How is “information literacy” interpreted in your library service? Does “The Framework forInformation Literacy for Higher Education; Association of College & Research Libraries (ACRL), 2016” guide information literacy teaching at your university?
10. What do other professional services areas (e.g. IT) offer in support of the makerspace?

    On site:
11. What do you consider are the main learning gains for students offered by makerspaceactivities?
12. What is the division of labour between professional staff and others in meetingstudent information and other needs related to makerspace activities?
13. Have different staff worked together in a new way in the context of supporting themakerspace?
14. Have any new practices or services been formed?
15. What do you think has been key to working successfully across professional boundaries to support makerspace activities (if this has been the case)? Are there particular academic areas that use the makerspace more than others, or particular projects/ activities yousee more than others? How is this evolving?
16. As well as face-to-face support, what support material (electronic or hardcopy) isproduced by the library or other services/ Academic areas to support makerspace activities?
17. From your experience how much makerspace learning is based on student peer topeer learning in the space or through online communities?
18. How much of the makerspace activity has a curriculum focus? How much could beconsidered cross-disciplinary?
19. What data do you gather from makerspace use (e.g. quantitative or qualitative dataon different types of users and their experiences, learning analytics connecting makerspace activities to course outcomes/ learning gains, other types of data)?

20. Do you have evidence of the gender balance in the makerspace?
21. Have you worked with other university staff to support makerspace activities? If so,how? What are the differences in terms of what is valued through makerspace learning?
22. What values and beliefs do you the think the makerspace promotes? Does this fit ininto your understanding of wider maker culture?
23. How does your makerspace link up with the wider ‘maker movement’?
24. What challenges remain in supporting and improving makerspace learning activities?

Interviews Schedule: Students

Key questions:

1) What subject/s are you studying?
2) Please tell a bit about your main goals and interests at university.
3) How extensively have you used the university makerspace?
4) What are your main motivations in using the makerspace?
5) Have you tended to work alone or in a group whilst using the makerspace?
6) Please give examples of some of the things you have made, and the technology you used (old/ new technology)?
7) How do you gather the relevant/ useful information for your makerspace activities?
8) How much of the information you need for your makerspace activities is obtained from peers (fellow students or communities of interest, including online), and how much is supported by academics and/ or professional staff?
9) What do you consider are the main learning gains for students offered by makerspace activities?

Additional questions:

10) Please focus on a difficult point (if any) in your makerspace activity where you stopped due to an information need. How was this resolved (e.g. searching a database/ the internet, asking for help)?
11) Do you think your information literacy and digital capabilities (including a deeper understanding of the digital environment, adaption and co-creation) are improved by makerspace activities? How?
12) Do fellow students provide direction and share 'know-how' on how to make best use of the makerspace?
13) How much do you learn in the makerspace from just observing others?
14) What kind of information and knowledge have you found you need most of for your makerspace activities? Where do you obtain the information (e.g. professional support staff, academics, online communities)?
15) Have you worked with students on other courses on makerspace projects? If so, what have you learned from these cross-disciplinary learning activities?
16) What values and beliefs do you the think the makerspace promotes? Does this fit in to your understanding of wider maker culture?
17) What is the main learning value (if any) to you of your makerspace activities?
18) Do you think your makerspace offers an inclusive space for learners (i.e. welcoming to women, and students from all backgrounds?)
19) What impact (if any) might participation in the makerspace have on your course learning aims and future interests/ goals?

Interviews Schedule: Academics

Key questions:

1. Please tell me about your subject specialism.
2. What courses do you teach?
3. Are you research-active? - If so, in what areas?
4. How does the makerspace fit in with your view of the role of the library service within the university?
5. Is the makerspace of interest to you and your students? If so, how? (If no please see questions below).
6. How extensively have you been involved with the university makerspace?
7. How (if at all) do makerspace activities create learning opportunities and positive outcomes for students?
8. Do you think information literacy and digital literacy/ capabilities (including a deeper understanding of the digital environment, adaption and co-creation) are improved by makerspace activities? How?
9. What information and knowledge is most of use for students to increase their learning affordances from makerspace activities?
10. Have you carried out any teaching sessions in or related to the makerspace? If so, please reflect on what (if anything) has been taught/ learnt.
11. What do you consider are the main learning gains for students offered by makerspace activities?

Additional questions:

12. How does learning in the makerspace relate to your pedagogical approach? (e.g. Do you like to encourage active learning on your course- discovery, invention, solving problems, creating knowledge?).
13. What to you is the main value (if any) to the students of taking part in makerspace activities?
14. Does the makerspace attract varied communities of practice?
15. How “authentic” do you think makerspace activities can be in terms of preparation forreal world/ careers?
16. Does the makerspace offer an inclusive space for learners (i.e. welcomingto women, and students from all backgrounds?)
17. What impact (if any) might participation in the makerspace have on your course learning aims and students’ future interests/ goals?
18. What data do you gather from your students’ makerspace use (e.g. quantitative or qualitative data on different types of users and their experiences, learning analytics connecting makerspace activities to course outcomes/ learning gains).
19. What values and beliefs do you the think the makerspace promotes? Does this fit in toyour understanding of wider maker culture?
20. What challenges remain in supporting and improving makerspace learning activities?

Interviews Schedule: Professional Staff

Key questions:

1. What is your role at the university?
2. Have you been involved with any makerspace activities?
3. How extensively have you been involved with the university makerspace?
4. Did the makerspace challenge your existing service aims? If so, did you manage to overcome initial tensions and challenges? How?
5. Have you been involved in supporting students makerspace activities yourself, if so in what ways?
6. How has supporting the makerspace challenged your established professional role (if at all)?
7. How do you support students with immediate information needs for makerspace activities?
8. Do have a particular pedagogic approach you favour for your information/ digital literacy teaching and training?
9. Do you think student's makerspace activities build their digital capabilities? In what ways?
10. What do you consider the main learning affordances for students offered by makerspace activities?

Additional questions:

11. Do you teach or support digital capabilities (such as the adaption and co-creation of digital objects and developing a deeper understanding of the digital environment) to students in relation to makerspace activities?
12. Do you tailor other support (not previously mentioned) for different students information needs to underpin the educational value of their makerspace activities to their course learning?
13. Are particular disciplines/ subject areas observed more than others in makerspace activities?
14. What kind of other learning opportunities/ possibilities do you think are most available from the makerspace?
15. What kind of information and knowledge have you found is most of value to makerspace learning?
16. Does the makerspace attract varied communities of practice?
17. Do you think your makerspace offers an inclusive space for learners (i.e. Welcomingto women, and students from all backgrounds?)
18. What kind of cross-disciplinary learning opportunities occur in your makerspace?
19. What data do you gather from makerspace use (e.g. quantitative or qualitative dataon different types of users and their experiences, learning analytics connecting makerspace activities to course outcomes/ learning gains).
20. Have you worked with other university staff to support makerspace activities? If so, how? What are the differences in terms of what is valued through makerspace learning?
21. What values and beliefs do you the think the makerspace promotes? Does this fit into your understanding of wider maker culture?
22. How does your makerspace link up with the wider "maker movement"?
23. What challenges remain in supporting and improving makerspace learning activities?

Appendix 3 - Research methods and full record of data collection

Research Method	**Time + Date**	**Key data focus**
Asynchronous email interview: Adrian (PRO/LIB/1)	20/5/19- 24/5/19	Building initial template from data from the makerspace project manager for areas to explore in more depth on visit
Direct Observation: English 101/019 Orientation in makerspace	21/10/19 09.35-10.25	19 Students observed learning key tools and starting to experiment
Documents: Quantitative Data Collection	21/10/19 10.30-11.30	Key makerspace service information/ quantitative data collected from library service (see Appendix 3)
Semi-structured interview: Charlotte (AC/STEM/1) & Miranda (AC/STEM/2)	21/10/19 12.00-13.15	Library makerspace service from Science academics' perspective
Semi-structured interview: Hazel (AC/HUM/1)	21/10/19 14.00-15.15	Library makerspace service from Humanities academic's perspective
Direct Observation: English 101/019 'Build Day' in makerspace	22/10/19 09.35-11.00	18 Students observed exploring the learning affordances of key tools for a class-based activity creating symbolic objects connected to real people or events

Semi-structured interview: Maddie (AC/HUM/2)	22/10/19 15.00-16.15	Library makerspace service from Humanities academic's perspective
Semi-structured interview: Peter (AC/HUM/3)	23/10/19 09.30-10.45	Library makerspace service from Humanities academic's perspective
Semi-structured interview: Marianna (PRO/STU/HUM)	23/10/19 14.00-15.30	Library makerspace service from participant with dual perspective of support worker/trainer and Doctoral student
Direct Observation: Making Space Event and makerspace workshop	23/10/10 16.00-18.00	Observation of outreach/ inclusivity event and workshop
Semi-structured group interview: Edward (STU/STEM) & Nathan (STU/PRO/STEM)	24/10/19 11.00-12.15	Library makerspace service from engineering student participants, one who has dual perspective of makerspace support worker/ trainer as well as user.
Semi-structured interview: Daniel (PRO/LIB/3)	24/10/19 12.00-13.30	Library makerspace perspective from professional librarian key to the inception and development of the service
Semi-structured interview: Jack (STU/STEAM/2)	24/10/19 13.15-14.15	Library makerspace service from perspective of Graphics Communications student who is also an entrepreneur

Semi-structured interview: Rachel (STU/STEAM/1)	24/10/19 16.00-17.00	Library makerspace service from perspective of Graphics Communications student who is also a maker
Semi-structured interview: Adrian (PRO/LIB/1)	25/10/19 12.00-13.30	2nd Interview with makerspace service manager
Semi-structured interview: Ivy (STU/STEAM/3)	25/10/19 09.30-10.45	Library makerspace service from perspective of Textile Design student
Semi-structured interview: Adrian (PRO/LIB/1)	5/3/20 17.00-18.15	Final (synchronous online) interview with makerspace service manager

Appendix 4 Examples of data analysis from interview transcripts and observation of activities

1st interview with PRO/LIB/1
Online interview with case study university makerspace manager 20-24th May 2019

Codes
Th:= Theme
Cat:= Category
MLA:= Makerspace Learning Activity/ Tools
LR:= Library and Learning Resources Support
T= Tension
C= Contradiction
E= Expansion
O:= Objective
A:= Aim, Outcome

21/05/19

1) Please briefly describe your role at the university.
My current title is Head of Making & Innovation Studio. I am professionally trained as a librarian and work within the [Case Study] University Libraries (**LR:** Expanding professional perspectives). I direct and manage our Makerspace program, which is situated within the Libraries and consists of two physical spaces, a full-time staff of 2.5 FTE, many student workers, and a large collection of technologies and associated services and learning experiences. My role is to direct this program in such a way that it has a meaningful impact on student success across the disciplines (**Cat:** Technical support, Tailoring makerspace activities, Division of labour staff/ students. **Th:** Experiential Learning and Maker Culture. **LR:** Support available from makerspace staff, Planning with Academics)

2) How did you get involved with looking after the makerspace?
I was a part of launching our Makerspace program in 2012-13 with our first space in the newly-opened [Campus 1 Makerspace]. But I suppose originally I got involved in this work because I was excited about the nascent so-called "Maker movement" and the growing accessibility of affordable digital manufacturing and physical computing tools (**Cat:** Maker Culture/ Movement). I had some experience with these as a hobbyist but saw great potential for them on the university campus and for the library's community (**Cat**: Expanding professional perspectives).

3) What were the most challenging aspects of getting the makerspace set up as part of the library service, and how were they overcome?

To focus on four main areas,

- Service Model: Figuring out how to make new kinds of tools and technologies accessible was a specific challenge, particularly with 3D printers (because of their consumable materials), electronics kits (because of their many parts), and electronic textiles (because you have to sew them into a project or garment for them to have use) (**Cat:** Technical Support, **T:** Supporting emerging and older technologies). These were overcome by iterative development —starting simple, evaluating what works and doesn't, getting feedback, and continuing to prototype new service models (**Cat:** Innovation through iterative development).
- Staffing: Running a makerspace effectively, especially if you want to do effective outreach and instruction to make its tools accessible, is very labour-intensive (**T:** Divisions of labour: staff/ students). This is also something that was overcome iteratively, by making do with what we had, and showing what opportunities were available if we could grow our staffing (**Cat:** Innovation through iterative development). Undergraduate student workers, and later graduate assistants, have been essential to the Makerspace program; but growing our full-time staff has made it much more impactful (**Cat:** Expanding professional perspectives).
- Instruction: Developing a pedagogical approach and a curriculum as well as a strategy for engaging our community (and importantly, University courses) has been a major and ongoing challenge for our project (**Cat:** Innovation through iterative development, **A:** Course-related activities). Again, this has developed iteratively, with input from many staff over the years and in response to direct feedback and other measures (**Cat:** Innovation through iterative development, Tailoring makerspace activities, Planning with Academics).
- Space Allocation: We started with a very small space in 2013, which limited our service model to a transactional one at the [Campus 1 Makerspace] (**T=** Initial lack of space). We were able to expand with a second space in our [Campus 2] Library (900 sq. ft), which allowed us to form more of an open workshop service model, and to expand our instructional program (**E/ O:** Expansion from initial 3d printing service to full makerspace, **A:** Learning affordances expanded across disciplines). Not long after, though, and continuing today, we have real challenges with the amount of space we have compared with the number of users and courses we are serving(**T:** Lack of Space).

4) How do the library makerspaces at [Case Study University] relate to other [Case Study University] makerspaces in terms of purpose and who uses them?

The primary differences are in access and disciplinary focus. Our library makerspaces are open to all NC State students, faculty, and staff, whereas many other spaces are only accessible to a particular College, academic department, or research group. (**O:** Expansion). Our spaces are intentionally interdisciplinary, while others exist within a discipline, (e.g. electrical engineering) or other specified focus (e.g., entrepreneurship) (**A:** Learning affordances expanded). We also have a traditional Crafts Center on campus, which is different in the materials/tools available (e.g. ceramics, kilns, woodshop) and in its costs (even students have to pay a monthly or semester membership charge).

5) How are you developing your collection of makerspace equipment in terms of additions to existing categories, or any new categories of tech equipment?
We hold a broad definition of making and focus on what equipment we think will be useful and impactful for our users across disciplines. So we don't always acquire tools which are exciting but require a lot of prerequisite and/or disciplinary knowledge(**E:** Expansion). We look for things that are accessible—usually affordable, and which have been designed with average users in mind rather than experts(**O:** Learning affordances expanded). Also, within the Libraries, we have parallel programs in support of both Digital Media and Virtual Reality, so we don't include much of those technology areas within the makerspace program.

6) What university clubs are based in or use the library makerspaces?
No clubs are based in the library makerspaces. We have collaborated with various student clubs, though, mostly by offering workshops specifically for their members, such as the Textile Engineering Society and Engineers Without Borders (**O:** Learning affordances expanded).

7) What have been the most successful library makerspace activities/ events over the last academic year?
Our biggest event of the year is Make-a-thon, which we have done 4 times now. I can get you numbers, but essentially we support 100+ students to work in interdisciplinary (interdisciplinary) teams of 3-4 on tacking sustainability issues over the course of a weekend (**O:** Events, **A:** Learning affordances expanded).

Some other highlights are 'After Dark', where we offered a lot of hands-on activities for our Friends of the Library, many of them alumni of [Case Study University] (**Th:** Partnership, Relational Work). We also hosted a "Repair Cafe," where students and others brought in broken electronics, garments and other items to fix in the makerspace (**O:** Learning affordances expanded).

Then also a big focus had been in supporting university courses in the makerspace, which we did throughout the academic year.

Supporting makerspace learning
8) What are the main skills required by the professional and paraprofessional staff that support the makerspace? Have there been tensions at all with adding more digital and technological skills to the academic librarian role, or were new roles required?
The paraprofessional staff require an advanced skill set, and they are classed as such. Their jobs combine customer service, student worker supervision, technical equipment maintenance, one-on-one consultations and group teaching, and more. They are required to make a lot of decisions and communicate at a very high level; and it's also very important that they keep the library's mission and our service goals at top of mind (**Cat:** Expanding professional perspectives).

As for the academic librarian role, there was no tension in our particular context, as our library as a whole had/has been moving toward more digital and technological services and the skills they require. Also, I and the other librarians who have been deeply involved in the project have all come to the organization through our Fellows program, which recruits newly-minted and high-achieving librarians to the organization. My role prior to opening the

Makerspace and for its first few years was "Emerging Technology Services Librarian," so that was a very new role, which was also open-ended in flexible enough to have space for the program to grow and take over most of my job (**O:** Learning affordances expanded).

9) What teaching/ training do librarians and other support staff offer to support makerspace activities (including teaching information, digital, technical, critical literacies)?

We offer a very robust program of workshops throughout the year on topics like 3D printing, sewing, electronics prototyping, screen printing, and more (**Cat:** Workshops, **LR:** Training sessions provided, **O:** Learning affordances expanded). Then also we do a lot of work with academic courses where we also teach similar tools and processes but adapt them to the context of the course and the instructor's learning goals (**Cat:** Tailoring makerspace activity, **MLA:** Planning with Academics). There is a lot of one-on-one, peer-to-peer learning that happens in the [larger] Makerspace, both by our staff and student workforce and organically among users of the space (one-on-one learning/ peer to peer learning/ student expert support/ staff expert support) (**Cat**: ZPD, **LR:** Peer to peer sharing, Support available from makerspace staff). We also occasionally teach sessions for faculty on how to integrate the Makerspace and its tools into their courses (**Th:** Partnership, relational work, **MLA:** Planning with academics). There are also lots of more informal learning that happens at events, via interactive displays, when we are out in the community, etc. (**Cat:** Maker culture, movement).

10) What do other professional services areas (e.g. IT) offer in support of the makerspace? How do you work with them?

The Libraries have both an internal IT department and also work with a campus-based IT department. We rely on them for most computing and software support, such as purchasing, licensing, some updates, networking and network security, etc. We particularly need them for the 20 laptops we have in our [Campus 2] Makerspace so that those machines have the software set up on them to work properly with our digitally-controlled tools like the 3D printers, Arduinos, digital embroidery machines, etc. They do not provide much in terms of supporting domain-specific software, but we do well to learn and resolve issues on our own when, say, needing to update the 3D printer software, add libraries for new electronics boards, etc. We meet with these folks regularly a few times a semester) as we have needs for new software or different access, or as problems arise, or as they need to change procedures due to new campus policies. This part of the project has had some challenges (**T-** Expanding library services), but generally, everyone is service-oriented and focuses on getting access for students, and that helps us get things where they need to be. We also have great support from the Libraries' Building Services team who have helped a lot with the building infrastructure, HVAC, shelving, etc.

11) What do you consider are the main learning gains for students offered by [Case Study University] library makerspace activities?

Learning particularly useful skills and tools, such as how to sew and how to use a 3D printer; a better understanding and consciousness of how things are made and how challenging it can be; higher-level knowledge such as design for manufacturing (manufacturing design), or how to best work within the material and precision limitations of a particular method/machine; how to use a prototyping mindset and iterative development process to bring ideas to life with feedback and testing; where and how to look for help, in the library and on the Internet; and hopefully, an understanding of libraries as spaces for learning, creation, community and support (**Th:** Experiential learning, **Cat:** Creativity & innovation through iterative development, Technical support, workshops, **MLA**: Iterative development of prototypes for course projects, Tool based activity **LR:** Support available from makerspace staff, Training sessions provided, Expanding professional perspectives, Online, Activities tailored to different disciplines, Accessibility, **A:** Learning affordances expanded across disciplines).

12) What do you think your library makerspaces offers that is specifically useful in supporting particular courses?

The main thing is our staff—we can lead sessions within a course on specific tools or methods so that faculty who are disciplinary experts don't need to learn those tools/skills well enough to teach them; then our staff are also available to help students in the course outside of classroom time during our open hours 70 hrs/week during the semester (**Cat:** Expanding professional perspectives, Co-teaching).

13) What are your librarians and paraprofessional staff able to offer that scaffolds makerspace learning that is different to or additional to IT or Academic support?

Are there any challenges in coordinating learning support between different university staff (IT, library, academics)?

I think a big difference is having the staffed space, and having it as a makerspace rather than something like a helpdesk. The space is welcoming and helps students grow in their learning beyond answering a singular question or need (**LR:** Accessibility). In using the space, they are exposed to a wide variety of tools and projects, and to our encouraging staff who are ready to help them one-on-one. It's also great that most hours of the week, the staff in the space are students themselves (**Cat:** Division of labour staff/students, **O:** Increase staffing with student workers), so they are potentially more accessible than full-time staff. There are certainly challenges, but we have enough autonomy and good enough relationships to make things work pretty smoothly. One consistent challenge is that the makerspace concept begs us to do things differently in a lot of ways: space design, furniture, computer security, tech lending—but I think this has actually been good for our organization and partners and has opened the door for other initiatives, such as our newer and really exciting Virtual Reality program (**Cat:** Expanding professional perspectives, **T:** Additional services developed).

14) What do you see as the particular challenges now that need to be addressed for your makerspace service in order to consolidate or evolve the service offered and expand potential learning gains?

Our challenges have almost always been space and staff (**T:** Lack of space, staff investment). Our ambitions are much larger than our capacity. We could really use a dedicated teaching space as well as a dedicated curriculum/instruction/outreach librarian to fully realize the potential of connecting the space with university courses (many more courses, focus on learning objectives with rigorous assessment, making this efficient and effective) (**T:** Showing academics makerspace possibilities). That work is very staff intensive, and with the space we have now, our regular drop-in use of the space competes with our teaching program as we need to close to other users whenever we teach. There are also some exciting tools (which would enable more ambitious projects) that would require more and dedicated space (e.g. a full CNC machine) (**A:** Learning affordances expanded across disciplines). There is also a need for more university-level buy-in and advocacy to grow engagement with the space. (**Cat:** University level support).

Interview with AC/HUM/1 21/10/19

- Please tell me briefly about your subject specialism and role at the university.

My name is [AC/HUM/1], I am an Associate Professor of English, and my background is in electronic literature and digital humanities. But I teach in the language writing and rhetoric division of English, so I teach mostly upper-division undergraduate writing classes in style and discourse analysis, and then I teach in the PhD programme rhetoric and digital media.

- How would you briefly define digital humanities?

I've thought a lot about this.. so the narrow digital humanities, kind of the original text, encoding, mark up born out of medieval studies. There is kind of the expansive idea of.. that's become more data-driven, interrogating existing texts, there is the circus tent which is electronic literature, digital art and the ways in which those are crossing over with digital humanities, and I'm in the circus tent. Although I've meddled in the other two as well. I'm also a digital publisher so I have a lot of technical background in web development.

- Do you think there is overlap between critical making and digital humanities?

Yes. Some critical making is about figuring out new approaches to traditional texts and old technologies in particular (**O:** Digital Humanities, Critical Making). I can think of one example, I'm collaborating.. I'm publishing someone who did a critical making study of Victorian-era muscle development kits, which are like electric shocks for your muscles that make you more muscular. He's a grad student in Canada, he's reproduced some of those and used them to think through ideas about, for example, Victorian masculinity. That's an example of a critical making project that I would call historical and interpretive. Then there's critical making when it's about producing new texts, as an English person I always think of texts so I can think of work that I've been doing and David Rieder has been doing in English as well using for example motion capture and accelerometer data to generate poetry or remix visuals and text and sound, some kind of multi-modal creative expression. One of the most interesting projects I've worked on has been with [AC/HUM/2], I think she may have been your initial contact. I am an electronic literature person, so I go to electronic literature conferences, and she is an early modern studies material culture person. So, we talked about building a critical making project a while back that satisfied research projects in both those a because that is what you have to do. And so we built this object called 'intimate fields' that's kind of a kit for putting together.. It's based around the early modern idea of the posy which is a really short little text that people would pass around as, like, love notes. So from her perspective as a literary scholar, she is interested in the posy as a genre and how that posy was embedded in material culture so gloves, stitched garments, rings.. that kind of thing. I was interested in a physical computing project that could take existing posies and remix themand produce new posies. The cross over technology that became the way we could think through it was the near field chip and the near field chip reader so, we had rings that had embedded chips in them we could put existing posies into, we also a set up where you could touch the ring to a reader that would generate a remixed new posy and then print it out on a little printer.

- How much of the activity around that project related to the library makerspace?

We did early prototyping, we were also trying to get the box, and it was bit of a failure (**MLA:** Tool based activity). The laser cutter had a whole stack of: here are the materials you can useand here are the thicknesses, then we picked one out, and then they didn't have it and they also said it didn't work with that material. So, we did it with another one, but it was the wrong size. We spent some time gluing it together in the makerspace. Ultimately, I orderedit from a commercial service because I couldn't get the thickness of the material I needed to make the box work in the way that I wanted it to work. There was a little bit of drilling, but that happened on my back porch so.. The technical materials were all stuff I was using for other projects so, they weren't from the makerspace. So the makerspace.. It was really only the box that was useful. I have taken students there, but that's another thing.

- How does your makerspace fit in with your view of the role of the library within the university?

I think it's kind of a neo-liberal space inside a neo-liberal space. So you've seen [campus 2 library] and [main campus library]. [main campus library] is spectacular, on a whole different level to [campus 2 library] is. But what they are about is recruitment and adding to the endowment, I think. Maybe I'm being cynical here, but I really think the glossiness of both those has more to do with public relations than it does with.. I think the makerspaces are now of the pinnacle of that come here, look, we have makerspaces recruitment. Makerspaces are where you can bring potential donors and say 'hey, look at all the cool tech things we are doing'. So I'm a little cynical about why it's in the library, even though I think that makerspaces are.. I like the material turn that libraries are taking in thinking about objects as potentially archivable and creatable, manageable in a library context, I think that's really cool, and that's possibly how the librarians themselves think of it as well (**Cat:** Expanding professional perspectives). But I do think there is also a PR funding to the way the makerspace has been put together, the shininess of it.

- Neo-liberal in the sense of an entrepreneurial, business focus?

I think that's a problem in critical making, not so much critical making but making as a culture more generally, it relies on certain kinds of expertise that are a little harder to transfer because they involve a lot of kind of finicky messing around. I say that as someone who works in critical making (**O:** Critical Making).

- How do you see maker culture as a movement?

This is why I was so impressed with Christine's dissertation ultimately, is that she sees.. Makerspaces have been around for thousands of years in the sense of specific spaces where people go to transfer expertise and knowledge about technologies. What's new is the idea of using objects to think about concepts. I think what appeals to me about critical making is it's like transferring the expression of knowledge from one modality to another modality. My colleague Rob Mitchell from Duke would call it material metaphor where you are using a physical object to carry a meaning from one kind of material space to another kind of material space (**O:** Critical Making).

- So what you are talking about is a less logocentric hermeneutic process?

Yes, but also sociological, Bruno Latour, Lucy Suchman. Thinking about things as ways of knowing the world. Using technologies to integrate the world and at the same time, construct it. So I think a lot of those materialist, new materialist scholars.. 'Vibrant Matter'.. I guess I'm coming at it from a New Materialist perspective.

- Do you think library makerspace creates learning opportunities?

Most of the interaction I've had with them was when I was teaching a class on critical making, so I brought them into the makerspace a couple of times, and the librarians ran really nice workshops on wearables, so we got to sow everything up. I was very grateful for the expertise of the librarians; they know how to run a workshop (**LR:** Training sessions provided, Workshops, Tailoring makerspace activity to course demands). I know how to teach a class, but I don't necessarily know how to workshop something like that. Afterwards, 3 or 4 of that group of 11 went back to the makerspace and ended up creating projects either consulting makerspace staff or making use of 3d printers and their sowing machines (**MLA:** Tool based activity). So one of the projects I have them do is where they have to create a biography of a person using no words, only materials, then they have to trade that with someone else, and that other person has to add an extra layer of biography onto the initial one which is super fun and also incredibly anxiety-producing for the students. It could be anyone as long as it's not a fictional character, it has to be an actual person, in part because fictional characters have such clearly defined arcs whereas real people don't, they have messy lives.

- Do you have anything you can share on these projects involving the library makerspace?

There was a student, who, she's been having medical issues. She was really interested in the idea of wearables, she started out as being interested in them as medical technologies. But then as we worked through the class, she started thinking of them as a kind of artistic ways of expressing the kind of human dimension of medicalisation. What it felt like to discover you had a medical condition, and she created this, it was beautiful, it was like a skirt, and you and all these little pockets and you could unclip the pockets and as you did lights came out of the pockets. I know she used the makerspace to work out how to stitch everything together, and I think she uses the materials from the makerspace, LEDs (**MLA:** Personal student projects). I think there is a lot of overhead with going to the makerspace and using materials and not being sure if you have to check them out or if they are consumables (**T/ LR:** Sustainability) what do you have to do with them afterwards? So one of the things I had them do at the beginning of the semester was buy a kit that was the Chibi lights kit which is little tiny sticky lights with carpet tape (they are maybe $25 per pack, so it is fairly cheap) as an alternative to a textbook and use those materials because they were their own, and they could destroy them and not feel bad about destroying them and also because they didn't have to go to the makerspace to make them, to use them (**LR:** Sustainability).

- So the makerspace here is a kind of try before you buy?

Yeah, or give them a sense of what's possible and then let them work out what they can do with the materials they have, and then if they want to use different materials that the makerspace doesn't have them, to be able to customise their work and materials (**Cat:** Technical support **A:** Learning affordances expanded across disciplines). So I think what was most valuable about the makerspace, that particular wearables workshop, was that now they understand how electricity works and how light sensors work. Once you have that kind of core knowledge, you can start thinking about how that translates to carpet tape and stickers. The conceptual.. combining the concepts with very clear examples. They made an example in the classroom, they all got to keep their Arduino Gemmas, that gave them a kind of a) conceptual understanding, and b) confidence to use materials (**A:** Learning affordances expanded across disciplines).

- Do you think information and digital literacy and capabilities are improved by library makerspace activities?

No. I think very specific skill sets or understandings of very specific small tools might, but you need a more expansive understanding.. The skills you need to work with eighteenth-century manuscripts are very different to the skills you need to work with electronics- those are both digital literacies, you are using your fingers, you are working with the material part of culture. I think what's useful about makerspaces is the opportunity to think about technology as being something you make rather than something you use (**O:** Digital Humanities, Critical Making). That's an important lesson because most students come in with their phone and their laptop. They don't really think much about how embedded those materials are or the fact they are made of materials even. I think you can't understand digital literacy without understanding the basis for that literacy. You can't understand a computer without understanding how magnates work and how the reason that 1s and 0s work and without understanding how they are embedded in trains of manufacturing, resource extraction and how screens engage a different part of our bodies than keyboards do. I think if more people thought about the material aspect of the digital ,they might be more mindful of how they use and dispose of their devices (**O:** Critical Making). So I think there is kind of an ethical issue there.. And the irony is makerspaces are really about consumables, you have those little Arduinos. I just finished writing a paper about the energy costs of making one Rasberry pi, for example- it's substantial! And makerspaces have all these kind of chips everywhere and that's a whole lot of embodied energy in one space, it's an incredibly wasteful space in terms of carbon footprint so my question is, is that the best way to do it (**LR:** Sustainability).

- What would be an alternative way?

I don't know paper computers!

- Do you see your makerspace related activities as part of 'maker culture', a challenge to it, or not a phrase you'd associate with your work?

I think both of those (**Cat:** maker culture/ movement). I'm working with someone from Washington state, we put together a journal issue for a journal that's fallen down a hole somewhere in their publication process. We spent a lot of time talking about how to uncouple, to decouple critical making in the sense of makerspaces and disrupt from responsible activities that might make people think. The difference seems to be there is no doubt makerspace silicon valley style is about selling you stuff and selling you a certain idea that you can just go and break shit. If you want to have a more responsible understanding of making you have to think about what the making is and does for the human biome, and whether it is necessary to have a space to do that thing (**LR:** Sustainability, **A:** Critical Making).

- What might a library makerspace offer that is different to from in a faculty?

I'm not a student, I can't speak to what students' innermost desires are. I don't know, would faculty make use of it. It's not like it is closed to faculty. We have one in the PhD programme called the Circuit Studio, and that got heavy use by a couple of PhD cohorts for a couple of years because we had made a specific effort to recruit cohorts who were interested in critical making. They produced projects, they published on projects, they were amazing! And then the next few cohorts have not been particularly interested. They are more interested in other things, whether it is big data, last year's cohort was really interested in social justice, this year they are interested in environmental justice. So I think you have to match.. You have to work to build a community around these things rather than working on the model if you build it, they will come (**T/LR:** Inclusivity).

- What do you think librarians are able to offer that scaffolds makerspace learning that is different to, or additional to IT or Academic support?

Librarians have an open an expansive understanding of how to interact with and share knowledge; librarians want you to know things and they work hard to help you to know things (**Th:** Partnership, Relational work). IT departments, their job is to lock everything down and to control it for good reason.. If you get hacked you ,are screwed. But, for example, we have word press installs that students have access to that help them to broaden their digital literacy in the sense of content management systems that they will likely have access to outside of the university. They are so locked down by IT they can’t run half the plugins, you can’t customise, so you only get a little tiny fraction. IT services are necessary because of the terrible world we live in, about controlling access.

- So if IT services are a service who are they serving?

The State.

- And of the library service is a service who are they serving?

The citizens of the State.

- And the Academics?

Academics are citizens of the state.

- But are they a service?

In the sense they are providing alternative modalities for our students to experiment with, I think that’s valuable pedagogically (**LR:** Resources tailored to different disciplines, **O:** Expansion from initial 3d printing service, **A:** Learning affordances expanded across disciplines).

- How might the library makerspace challenge the white male demography often found in makerspaces?

One of the things.. I haven’t been to the makerspace in like a year and a half or so, but one of the things I noticed the last time there was a 3d printer like the big cool thing, and they have some embroidery machines that are kind of stuffed in a corner. You need more space for the materials and the tools that are available like sewing machines, you’ve got to pull them out and set them up and have space to sit for pedals, and you know, hook them all up (**T/LR:** Accessibility). The 3d printers are already hooked up and taking up two-thirds space easily, it’s too small (**T:** Lack of space, **LR:** Inclusivity). You go to the craft centre the road and it’s a massive building. It’s got a room that is just for looms, it’s got a room full of spinning wheels. Students can use it, they'll to go through orientation and have a specific need. They have extension classes, but they are more for use outside the classroom than specifically for pedagogical use.

- Where does the library makerspace service need to go now?

So, I think it needs to be bigger (**T:** Lack of space). I think there needs to be dedicated subject experts for specific kinds of technologies that are.. sometimes you get machines in there like the embroidery machines I’ve used a couple of times and ask, ‘can you teach me how to use this’ and they’ll be like one person who’ll be like, ‘I think I can figure out how to use that and maybe I can show you’. But wouldn’t it be great if you actually had, kind of like subject librarians, but for specific clusters of technologies. (**T:** Support available from makerspace staff).

- So if you were clustering technologies, would they need to be around academic perspectives or the technologies themselves? Do you start with the technologies, or with the framing?

That’s a good question. Do you know Ann Shivers-McNair’s work? So ,she’s a rhetorician that came out of Michigan who wrote her dissertation on makerspaces, she’s at one of the

UTs now I think, and her thing she went to a local makerspace and strapped a GoPro to her head and watched everything that happened. It's great, really cool, there is this video. And one of the things that she was very careful to do was trying to understand how makerspaces were reforming themselves in the spaces they had, she noticed over time technologies migrating towards each other in kind of logical use clusters. She noticed furniture moving in order to accommodate how you use the technology. So, she watched it happen as a result of use rather than design. It's like desire lines. I think you need the space to cluster them, you need the space to be able to move the objects from one place to another, and if you lock them down they are always going to stay in that space even if it's inconvenient for the actual users (**MLA:** Tool based activity, **MLA:** Emerging new and older technology, **T:** lack of space, **A:** Humanities lab and engineering, STEAM).

- So are there any other aspects of the library makerspace service that need to be expanded?

Well, as I said subject librarians, you'd have to figure out what those subjects were obviously. Maybe you could have like artists in residence. I know the visualisation spaces over at [Main campus] library have just got this grant a couple of years ago, called immersive scholar, they set up this whole thing, I was on the board of it. People applied from all over the world, they came, and they made use of the visualisation panels over in [Campus 1]. You could do that with a makerspace- have a fellowship, bring people in, with expertise, have them run a few workshops, have them produce exemplar materials. That takes money, it takes money (**T:** Lack of investment]. There needs to be more fluid understanding with what you do in the makerspace. One of the things that I like here was, I went to, like, a little bookbinding. It was in the makerspace, you know, there is no reason you couldn't learn to sow and spin and do other kinds of technological things in the makerspace. That's been pushed off into the craft space. Cooking is making, right (**MLA:** Tool based activity, **MLA:** Emerging new and older technology, **T:** lack of space, **A:** Humanities lab and engineering, STEAM).

- Does the critical aspects of making rely on the space where things can be critiqued?

Electronics have their own aesthetic, they have material needs, 3d printers have their own needs and aesthetics (**T/MLA:** Tools based activity, **T/E?:** Additional services developed).

- Can librarians be more involved in critical making pedagogy?

In terms of movements in scholarly research generally I feel critical making is a little past its prime. I can't speak internationally, but nationally I've noticed a recent move into animal studies, eco-criticism. One question would be whether you can harness the makerspace to think about some of these issues (**T/LR:** Accessibility, Inclusivity, Sustainability). If it was me I would hook up the makerspace with the ice cream parlour down here and start doing interesting things with ice cream and food printers. I mean we're an agricultural school, you could do amazing things with makerspaces and agricultural technologies. [Case study university] was born out of.. It was a land grant institution, it's got a massive vet school, it's got programmes in turf management. It's got kind of a big STEM, and liberal arts, but it's still strong on agriculture and it would be nice to see that element stretch out into other colleges. I just went to and then gave a presentation on bio art, they have this really great thing that's different pieces of bio art and that was sponsored by the centre for genetic futures, a cluster.. So, it's a collaborative interdisciplinary group. Those groups I can see as being great in taking agricultural routes in biology and pulling them over to humanities or STEM. One of my best students was a turf management student, an undergraduate, and he actually made use of the makerspace. He was doing genetic engineering of wheat in his own programme and so he did some writing about wheat ; I think he might have done something with plants. That was a couple of years ago though (**T/A:** Learning affordances expanded across disciplines).

Interview with STU/STEAM/1 22/10/19

- Please could you tell me what subjects you are studying?

I'm a graphics communications major. So, I'm doing a lot of things dealing with graphics work. So, the last class I was in digital design, so we do things with illustrator, all the Adobe products, so illustrator, photoshop and in design. Another class I am in is for architecture and we use Autocad. I'm taking an advanced Solid Works class. I'm taking public speaking which is where the communication comes in and I'm taking a lab where right now we are building a box, they have wood tools in there, metal working tools and 3d printers and laser cutters. So, it is technology, design and engineering education. So, basically they are teaching us a whole bunch of different skills we can potentially use if we wanted to go into industry or if we wanted to teach STEM classes. So, all of those are like engineery, STEM things.

- Do you have an idea now which direction you would want to take?

I don't want to teach. If I taught I would probably like.. I'm sort of deciding what to do. I've always wanted to go into industry and make products for companies whether it be logos or like actual products, tangible items. But I am starting to think I could go down the research path with STEM education and to become a Doctor and teach college students, I don't think that would be bad. But I wouldn't want to teach K-12.

- So how have you used the library makerspace?

I was an industrial engineer in my freshman year here and we have a thing at [case study university] called FEDD day so first year engineering design day, so you are required to make something to solve a problem, and they have a list of problems you can choose from and you are required to have an orientation at the makerspace, and my team ended up using the makerspace to make our product (**A:** Coursework related activities). So, I signed up to do the 3d printing project and the goal of that project was to make something a family can take on vacation that has multiple uses. So we decided to make a carabiner for a camping trip, the clip.. There's one on my keys.. This is what.. So one of those and in order for it to have multiple uses we put a compass, a ruler and a bottle opener as well as the clip so it had four different uses and then we 3d printed that in the makerspace.

- So how many of you were in that project?

Our project.. I think we had teams of four. So, I designed it using. It wasn't Solid Works, it was Fusion 360, and then we printed it downstairs in the makerspace.

- Have you used the space since?

Yeah, so I broke my phone charger, so I went in there and fixed my phone charger, I fixed a bunch of wires. I have an Apple phone and apple chargers suck, they always split so there was like wire sticking out, so I think I put solder on the wires to make it go back together, and I wrapped it up, and I put a heat shrinking tube on it and all that material was supplied (**LR:** Sustainability). I recently went back to do a project for my public speaking class, so we had an orientation there and then I did something in there, I can't remember.. We went and took the orientation there and that was the project.. and that was like our experience from that class, but then I went back there.. I think I did something, I, like, used a piece of wood, I was playing around with a piece of wood to make it like a gift tag for someone. It was a really small thing; it wasn't for class or anything (**MLA:** Personal student projects).

- So I'm interested in motivation, you've given examples of class-based use but how would you describe your motivation for the other makerspace activities, was it fun?

I think it was need to, I wanted to make this gift for this person, and I think I couldn't think ofa better way of doing it. I didn't have the tools at home to do it, otherwise I would have just done it at home (**MLA:** Tool based activity).

- And it worked out, the gift?

Yeah, they just thought it was cool, it was not a big deal for them.

- I'm interested in whether your makerspace project was more as a group or individual activity?

So, we made the project as a group, but I went in and printed it. You don't really need four people to use a 3d printer. So, I designed it and we all talked about it, they did some stuff with the poster board, but I went in there and I printed it. I also had 3d printing experience, I knew what I was doing. I was on the robotics team in my High School and the team brought the printer for our team to use so I learned on that and then, my friend got a 3d printer, a new better one and gifted me the old 3d printer. So, I was able to use that for a while until it broke.

- Would you say you are involved in wider maker culture yourself?

I would say so, yeah, I enjoy making things. I really love 3d printing, like learning all about that, that's what I really enjoyed in industrial engineering all the processes they talked about. Like, switching over to TDE, I really like.. We are making a box right now, a wooden box, so learning about all of the tools, being able to use them safely and well, to go from an idea and draw it to it's an item you can hold with your hands. So that whole process, it's really cool (**MLA:** Tool based activity).

- So when did you start making?

Probably in High School when I joined the robotics team. We were given a challenge and we had to build a robot for that challenge. We were thinking I can solve it by doing this but how can I, I as a human can easily do that, but how can a make a robot do that. You would be thinking these things and actually have to put in action. So, you would put it in Solid Works and make animations to see how it would work and then get the parts, build it, test it, things like that (**Th:** Experiential learning and maker culture).

- So what are the technologies you have used in the library makerspace?

3d printer for sure, soldering irons, I think I used the vinyl machine here. I know I used one at High School, I can't remember.. I did not use the sewing machine!.. All the electrical tools I played with, so the heat gun, the soldering iron, the wire clippers. I think that's all I've used downstairs (**MLA:** Tool based activity).

- Where would you find useful information whilst using the library makerspace?

It's nice because they have, there's always someone whether it be a student or one of the adult workers in that space. I don't like asking for help though, so usually I'll Google it.. so there'll be like flashbacks to past experiences, so it will be like oh I know someone who did this to fix this problem.. But if it comes down to it they are right there, you can just ask them (**LR:** Technical support).

- So if you go online where would you look?

I just type it into Google and look at different forums. Forums are probably the most usefulbecause everyone's discussing, they are going back and forth. Nobody has the exact same problem as you, but you can usually find one that's close enough so you can solve it. (**LR:**Online)

- Do you use YouTube?

Sometimes, yeah.

- Do you use any of the library resources?

Just people. It's quicker. (**LR:** Technical support)

- Do you ask other students for information?

I definitely remember for that one project that I did for the FEDD day I asked students before I asked the workers. So, if you are sitting around, if you are doing something with the printer and I'm having trouble with mine, I'll go 'hey, can you help me' and everyone is nice here, so they do. I don't like asking for help, I'll ask a student before I'll ask an adult (**Cat:** ZPD).

- What would you consider to be the main learning gains for students from using the library maker space?

I think the fact that you can make things yourself, like, one of my friends is in that TDE class doing the wood project and she just gets really excited, she's like 'I actually made this, I used this too', things like that. I've seen that in the space downstairs, just the fact you can have an idea and you make it (**Cat:** Creativity and innovation, Maker culture). I think also, because, like, bringing women into this to, my friend is like my Dad told me how to do this but never let me do it, my brother always did it. So, like, for her to be able to get her hands dirty, and work on it and do it. It's, like, empowering, it makes you feel good (**LR:** Inclusivity).

- Does the library makerspace offer something different? Would you feel comfortable in any of the [case study university] makerspaces?

I would say so. You know going in that everyone is at different levels of knowledge for using different things, like I know 3d printing well but I don't know how to use a laser cutter. But also know that's ok, there's people there that can help you, and the library sends out so many emails.. about orientations.. And come in and learn to use the sewing machine.. And we're doing this Halloween themed project called.. try it.. So they definitely market themselves to be diverse and inclusive (**LR:** Inclusivity, **A:** Learning affordances expanded across disciplines). I've been in the entrepreneurship one and it is huge, it's like the TDE lab, there's a lot of, like, bigger machines, like a router, table saws, drop saws, things like that? I think the makerspace [library] is for, I don't want to say smaller projects, but for electronics, like, a condensed project (**T/Cat**: Entrepreneurship). Or like 3d printing, smaller condensed projects, if you.. You can't really go in there and make a box.. You don't have the tools in there in to do that. But if you wanted to bring a box, or a piece of wood from outside to work on it specific, or like, concentrated, you could, like laser engrave it or.. Something like that. I think the same principles are there though, you can come in, you can make things and you can learn things with what we have provided. The things provided are just different (**T/A:** Humanities lab *and* Engineering).

- What would you like to see from the library makerspace in terms of its evolution?

I would definitely like to see it bigger, it's very small (**T:** Space). And part of it being small is it has to be closed for orientations or for when they throw events, so a lot of times when you want to get to work on things its closed for an event (**T/LR:** Space/ Inclusivity). If you had a larger space, you could like cut the room in half and half could be working and half could be the event, an orientation or something like that, which is actually what we are doing with our TDE lab, we are cutting it in half with a glass wall so a plastic or acrylic wall, so you can still see what is going on, but one side would be for classroom and one side would be for working.I think that would be an improvement. I think the resources provided, there are lots of cool resources there, so I think that's fine.. If you had more room you could definitely fit more stuff in there or even maybe bigger 3d printers, because the things they have now are like 6 by 6-inch cube and sometimes you want to make things bigger than that, so maybe have like two bigger 3d printers, that would be really cool (**T/A:** Humanities lab *and* Engineering).

- Are there ways the library could make you more comfortable in asking for help?

I know the makerspace has a website, it might be useful to have machines listed there but also commonly asked questions, commonly seen problems.. So like your filament gets stopped what do you do… like on a FEDD day it's not just you and your team working on a problem it's all first-year engineers working on projects, so the makerspace is crazy, it's always packed, so if one person is helping someone else, so now you have a resource to go and search it instead of waiting (**Cat:** Technical support, **T/LR:** Online, Accessibility)

Observation of makerspace activities (October 2019 visit)

Makerspace Field Notes Template

Date/ Time:

Site:

Activity:

Participants:

Length of Observation: 1.5 hours

Observations/ Summary:

Analysis to include:

For non-structured makerspace learning:

- find out what project/ activity students are working on
- how do students use and move around the space?
- what tools do they use (physical and electronic), and how?
- what are students working on?
- how do students observe and learn from each other?
- how they are working together (are groups forming, how are tasks divided)?
- what information are they sharing/ using?
- what support do they ask for/ is offered to them?
- how are stuck points in activities resolved?

For teaching/ training in the makerspace

- what is being taught (including the lesson objectives), and who is doing the teaching (e.g. academic, professional staff, student)?
- what materials/ tools are used?
- are specific learning needs taken into account?
- is "what has been learnt" reviewed at the end?
- how much of the teaching/ training is imparted through demonstration and activities?

- does the knowledge imparted appear to be relevant to the students/ connected to previous learning?

- what questions are asked by the students doing the session?

- how are any difficulties/ immediate information needs resolved?

- any other notable aspects of the learning or teaching in the makerspace?

Build Day Eng Tue 09.30 22/10/1 am

Key observation notes
PRO/STU/HUM introduces the following to all in makerspace, makerspace is full:
STL files
Tinkercad.com
Thingiverse.com
Digital embroidery (templates)
Laser cutting- SVG files (**Cat:** Technical support)
Student already starts making as Mariana talks (cogs in a wheel - using plyers to remove excess plastic stopping wheels turning)
Sewing mentioned by PRO/STU/HUM (**MLA:** Older technologies)
Students grab 3d pens
Mariana talks to student about sowing/ choosing fabric, different materials, what's available, different colours for 3d printing (**Cat:** Technical support, **LR:** Resources tailored to different disciplines)
One student has a portfolio book of drawings, diagrams and photos
Others using laptops
Teacher tells students who seem anxious 'this is not a high stakes design' (**LR:** Accessibility, Inclusivity)
Mariana shows Tinkercad (**Cat:** Technical support)
6/7 students doing 3d printing
Student email login for Tinkercad- lots of examples (**Cat:** Technical support)
Mariana talks about thinking in 3d rather than 2d (**Cat:** Technical support, **A:** Learning affordances expanded across disciplines)
People using Tinkercad during talk
Others involved in other work, not all doing the same Tinkercad activity as PRO/STU/HUM
PRO/STU/HUM shows grouping/ colour/ measurements in millimetres/ increasing and decreasing size of shapes/ creating holes- more attention from students as it gets more complex (**Cat:** Technical support)
PRO/STU/HUM shows moving from solid to hollow objects/ adding text/ create hole in object for text
One person still sewing
PRO/STU/HUM shows buying STL files in from thingiverse/ example of cat going bigger or smaller/ loading transformer like object/ helping with 3d printing (1:1) (**Cat:** Technical support)

After presentation: PRO/STU/HUM helping students. I talk to the following students:

1. Student trying to decide on project- meaningful object with paper explaining process/ meaning. Idea of human dependence on violence from 2001 Space Odyssey/ symbolic translating to physical (dawn of man sequence). (Male, White)
2. Student who has printed an apple tree/ apples/ will then print a table. Symbolic of immigrants work for the 'high social table' whilst they don't get to eat on it themselves. Influenced by song from Hamilton 'Immigrants (we get the job done)' - Lin Manuel Miranda. Working for poor pay- evocation of apple and tree image. (Female/ Hispanic American).
3. Student trying to make a wing- wing of Icarus from the painting by Bruegel: 'Landscape with the fall of Icarus'. Meaning and process still evolving. (Male, White)
4. Student with journal with hand drawings and designs is from the Design School planning a design for a project which she expects will result in an object to be displayed on campus with a practical as well as symbolic message about sustainability- a rain pavilion made entirely from discarded plastic bags. Working on drawings and design at this stage(Female, White).
5. Student making a design for a mask to make on the 3d printer showing a happy and/ or sad face, this looks similar at this stage to some of the Ancient Greek masks used in theatre. Project about how we hide behind fake emotions. At present using cut out from images of a sphere to create a simple design for a smiling face (Male, White). (**Cat:** Creativity and innovation through iterative development, **MLA:** Iterative development of prototypes for course projects/ Personal student projects **LR:** Accessibility, Inclusivity, **A:** Learning affordances expanded across disciplines, STEAM)

PRO/STU/HUM showing some more on Tinkercad, also walking people through Cura: http://cura.design/ (**Cat:** Technical support)

Students exporting to STL- six 3d printers available. PRO/STU/HUM emphasises this 'is not a competition'. (**LR:** Inclusivity)

PRO/STU/HUM explains students can share a build plate on the 3d printer for smaller objects. Print cost- filament measured in grams- student wants to print in green. Objects can be rotated, or image mirrored. Support needs to be generated for more fragile objects so bits don't fall off (software indicates if printing will be successful). Options of standard or high detail print. (**Cat:** Technical support)

Some people ready to 3d print/ Student still with sewing activity.

Teacher wraps up. Students can stay in the space. Students put hands up for help after the class ends - PRO/STU/HUM helps.

Someone from the genetics lab asks PRO/STU/HUM about creating material object as a component part of a heavy lid for equipment. (**Cat:** Technical support)

Student still pulling bits of plastic out of the wheel with cogs with plyers. Some movement with cogs before she leaves.

(*Observation- makerspace shows what is possible for symbolic and/ or functional designs. Thoughts and feelings expressed in embodied action and material form*).

Observation from PRO/STU/HUM after session: Physical process helps the writing process- students need to be exposed to creativity, different modes of communication, multi-modality, also expected in industry.

Appendix 5 Template Analysis

Template Analysis from initial data collection:

Themes	**Categories**	**Makerspace Learning Activity/ Tools**	**Support for Information Needs**	**Service Tension/ Expansion?**	**Objective: Service Action/ Division of Labour**	**Aim**
Experiential Learning and Maker Culture	Maker culture/ movement Creativity & innovation through iterative development Zone of Proximal Development (ZPD) Technical support Workshops Entrepreneur-ship	Iterative development of prototypes for course projects Personal student projects Tool based activity	Support available from makerspace staff Training sessions provided Peer-to-peer sharing Online	Lack of: Space Staffing Investment	Expansion from initial 3D printing service to full makerspace Increase in staffing through student workers	Learning affordances expanded across disciplines

Partnership/ Relational work	Co-teaching University level support Tailoring makerspace activity for course demands	Planning with academics	Resources tailored to different disciplines	Showing academics makerspace possibilities (e.g. for PBL)	New coursework makerspace related projects Events	Coursework related activities
Contradictions / Tensions **Library Services Expansion**	Division of labour- staff/ students Expanding professional perspectives	Emerging new and older technology	Accessibility Inclusivity Sustainability	Additional services developed	Attracting all student types Digital Humanities Critical Making	Humanities Lab *and* Engineering STEAM

Final Template Analysis:

Themes & Sub-Themes	**Makerspace Activity**	**Tension/ Contradiction**	**Library Support Objective**	**Outcome**
Maker Culture Variable Awareness & participation in Maker Culture Digital Humanities & Critical Making	Tool based maker activities including: 3D Printing Laser Cutting 3D Scanning Electronics Robotics CAD Sewing	Variable participant awareness of and interest/ involvement in 'maker movement' Critical view of Maker Movement from Digital Humanities and Critical Making perspectives	Broad church approach with different perspectives on maker-learning welcome	Evolving service through faculty outreach with humanities as well as STEM and STEAM
Experiential Learning Embodied Learning-by-Doing Social Learning & ZPD Iterative Learning from Mistakes	Iterative development of prototypes for course projects or personal 'passion' work Group work & learning from more capable peers Experimentation encouraged	How practical/ real world are these activities?	Library support guided by course aims and partnering with faculty	Faculty & learner defined learning outcomes

Relational Work Evolving Learning Communities Library Maker Community HEI Inward Focus	Making Space programme Informal makerspace-based community	Lack of makerspace-based interest groups	Expanding from traditional STEM makerspace through relational expertise Supporting new communities of practice	Ongoing challenge/ opportunity Self and group-efficacy with creative maker activities
Cross Disciplinarity: Learning Models Social-Constructivism Embodied Learning Technical and Interpretive Support Individual Creativity and Innovation Critical Making & Digital Humanities Critical Expansion of Digital Literacy	Individual and group learning scaffolded by library makerspace staff and student workers Makerspace staff recruited from students with technical & communication skills Process Orientated Guided Inquiry Learning (POGIL- Constructivist teaching method used by STEM academics) English Critical Making and Digital Humanities maker coursework	Balancing needs of STEM, STEAM & Humanistic pedagogy	Showing some academics the makerspace has more learning possibilities than they imagine for ethical, embodied, haptic, reflective maker-learning across disciplines	Ongoing challenge/ opportunity Disciplines learning from each other's different ways of knowing

	supported by library staff			
Inclusivity and Sustainability Maker Identity Library Inclusivity Affordances Accessible Technologies Expanding the User Base Sustainability: Financial, Environmental	Making Space programme 'Make-a-Thon' (environmental focus) Proactive engagement from library staff with non-STEM students Interest in further developing outreach to students from less privileged backgrounds	Lack of space, staff and investment for further expansion	Further outreach to all faculties, with new co-teaching pedagogies, coursework and workshops developed More inclusive activities planned: encouraging, supporting and empowering all types of learners	Ongoing challenge/ opportunity Makerspace as a key higher education learning environment for socio-critical material awareness

Appendix 6 Notes from shared documents, data and online information

Current service offer:

- 58 current makerspace workshops including 3D printing/ scanning, Sewing, Arduino, the Internet of Things, Digital Embroidery, Coding for wearables, Circuits and soldering, Design Thinking, CAD, Digital Sculpting, Bookmaking, The Art of Making Data, Critical Making for Sustainability, and The Future of Making Things in the Classroom.

- 49 current course-based Instruction courses including: Technology in the Arts, Studies in Rhetoric and Digital media, Internet and Society, Big Data, Science Fiction and Steampunk, New Media and Contemporary Art, Communication for Engineering and Technology, Fashion Product Development, Advanced Graphic Design Studio, Horticultural Science, Biomedical Engineering Design and Engineering Entrepreneurship.

- Outreach activities including: EcoVillage, Music technology, Make-a-Thon (Sustainability focused), Minority Engineering Programs, Arts Village and Women in Engineering.

- Technologies available for use including these categories: 3D printers, Tools, Laser cutters, 3D design, Sewing, Electronics, Soldering, Milling, 3D scanning. Virtual reality was popular enough to create a separate space and service.

- Technologies for borrowing including: 3 printers and scanners, Arduino inventor kits, Internet of Things starter pack, iRobot Create, Raspberry Pi, Sphero, and Sparkfun RFID starter kit.

These are notes are in sections with factual information about the case study makerspace maintaining anonymity:

University Facts

- More than 34,000 students from 119 countries including over 9900 graduate students
- Total campus area covers 2100 acres, plus over 100,000 acres in farms, forests and other research facilities

Colleges

- Agriculture and Life Sciences
- Design
- Education
- Engineering
- Humanities and Social Sciences
- Management
- Natural Resources
- Sciences
- Textiles
- Veterinary Medicine
- First-Year College
- Graduate School

Vision

University vision: To emerge as a preeminent technological research university recognised around the world for its innovative education and research addressing the grand challenges of society.

Innovation statement: Economic growth and strength depend on the ability to innovate. For 125 years [case study university] has been at the forefront of innovation - in our educational methods, in industry partnerships that drive discoveries to the marketplace, in research that improves lives.

Case Study University Library Service Vision: Leading edge of research collections, innovative learning spaces, and user-centred services to support the university's vision and further knowledge in the world.

Library Makerspace Service vision: At its core, the program is one of Access (open to all, usable, supported) and Literacy (Digital, Technological, Conceptual- processes, 3d printing, data, knowing how things are made).

PRO/LIB/1 personal professional library ethos prioritized:
- Democratizing access
- Public service
- Community centers
- Lifelong learning
- Outreach
- Librarian core skills of information literacy, organisation and navigation of information, the research process, and connecting people

Tips from PRO/LIB/3 'Growing a Makerspace at [case study university] library' presentation:
- Think beyond buying the 3d printer to the user experience, service, access and maintenance
- Make connections on campus
- Start small, let it grow
- Capture and tell users' stories
- Connect your librarians to your donors

Example Maker Course: Digital History - Theory and Practice
Learning Goals:
- Use the library's affordable 3d scanning to scan artefacts (e.g., 18th Century Butter Print, 2014)
- Publish scans with written reports on the artefacts to the Wed
- Learn about the efficacy of current technologies, and implications for the future.

Library Services
Two main libraries and two smaller subject specific libraries (Natural Resources and Veterinary Medicine). Over 2.5 million total user visits per year.

Learning spaces: Learning Commons, Faculty Research Commons, Graduate Student Commons, Large-scale high definition visualization spaces, Digital Media creation facilities, Specialised areas for creating simulations and virtual environments, Gaming spaces including Game Lab for the scholarly study of games, iPearl Immersion Theater for the panoramic display of faculty and student work, Special Collections Reading Room and Exhibit Gallery, and Makerspaces with 3d printers and scanners, a laser cutter, electronic kits, soldering irons, and sewing machine.

Collection: Strengths in agriculture, architecture, biological sciences, design, engineering, entomology, forest resources, mathematics, physical sciences, statistics, textiles and veterinary medicine. More than 5.2 million volumes, approximately 100,000 print and electronic serial subscriptions (99,000 of them electronic).

Making Space Event Series
Making Space aims to confront bias and systematic barriers to inclusion in the STEM fields by presenting the experiences and perspectives of underrepresented groups in science and technology, including people of all identities and abilities. Through a series of public talks and workshops, the program series centers gender diversity and inclusion in STEM, as it intersects with race, ethnicity, ability, and sexuality.

The Library service works closely with the Gay, Lesbian, Bisexual and Transgender university community and a 'Raiders of the Lost Arcade' Making Space event explored queer narratives and experiences through video games. Making Space guest speakers have included female STEM professionals sharing their career paths facing bias and systemic barriers.

2016 data showing more inclusive makerspace activities included a Creative Coding Workshop (70% Female, over 50% humanities and design studios) against other data showing the typical male STEM bias such as a Creative coding Hackathon (90% make, 80% computer science students). A Creative coding lunch group showed a 50/50 female to make ratio.

Outreach partnerships/ courses encouraging women in STEM/STEAM and inclusive humanities projects included:

- Woven Textile Design Studio
- Technologies and pedagogies in the communication arts
- Introduction to Digital Humanities
- Interpretive machines
- Site design and construction
- Exploratory studies
- Communication and technology
- Special studies in textile engineering and science
- Fashion product development

Accessibility
Accessibility and Assistive technology consideration encouraged library makerspace events and activities including having various activities, asking participants for accommodation and feedback, labelling tools and ensuring many have rubber grips, having guides, rules and documentation in a variety of formats and training/safety videos.

Health and safety- Each makerspace has a Safety Plan. Staff are regularly trained in the execution of the Safety Plan. Makerspace users are required to attend an orientation which includes training on safe use of the space and its tools. Key policies include:

- Use of outside cutting tools is not allowed in the makerspaces
- Only qualified full-time staff members are allowed to use the laser cutter, unless explicit and project-specific permission is given by such a staff member.
- Makerspace users agree to this statement: "I warrant that I am authorized to use the applicable files, data, images, or any other materials (collectively 'content') in the makerspace and that the use of the content will not infringe upon any third-party's copyright, patent, trademark, trade secret or other proprietary or intellectual property rights.

- Makerspace users can only use one 3d printer at a time
- Makerspace users are expected to use the makerspace for lawful purposes that respect the safety and well-being of all students, faculty, staff and patrons. In particular it is prohibited to use the makerspace equipment to create any objects that engender anyone, including weapons.

Make-A-Thon
Yearly weekend event in February where students look to find solutions to a more sustainable world. During this three-day challenge student teams research, design, prototype and build a new solution that addresses a sustainability challenge. On the last day community and industry sustainability experts evaluate solutions and award prizes to the top teams in each category, as well as a grand prize to the overall winner. In 2019 winners walked away with nearly $5000 in cash and prizes.

2019 Winner: Smart windows that adapt to the changing level of sunlight. In this energy-saving system, window shades and indoor lighting would automatically adjust to the level of sun, providing the optimal level of lighting for building occupants.

2nd Place: An Internet-of-Things connected sensor that could help save $300 a year in residential water use. A companion app challenges users to save water while Machine Learning helps identify water leaks before they become major water wasters.

3rd Place: Recycling requires a market for the recycled material. If recycled plastic is integrated into a type of pre-made concrete mix, this could reduce plastic waste while also simplifying the plastic recycling process.

Notes from PRO/LIB/1's 'A vision for the future of Makerspaces at [Case Study University] Libraries October 2013

The initial Campus 1 library service makerspace was a success, garnering media attention, the 3d printing service printed over 600 models for over 200 individuals. The makerspace gives all students and faculty access to the transformative new technologies of digital fabrication.

The makerspace enabled the following projects:

- Tactile maps for blind pedestrians
- A Biology instructors geometric models of viruses used for teaching their structure
- Engineering Entrepreneurship Program team's prototype for their Jar with a Twist product that made national news

The opening of a second makerspace at Campus 2 will build on this success by expanding the Makerspace program not only with a new location, but a broader set of services and a broader approach.

Guiding principles:

1. Provide emerging technologies for making in new, digitally-enhanced ways such as 3d printing, 3d scanning, laser cutting and more.

2. Democratise access to these technologies on campus by making them available to the whole university community.
3. Support hands-on, project-based, and interest-driven learning- a powerful way for students to learn next-generation skills.
4. Serve as a competitive advantage for anyone seeking to innovate, for students entering the job market, and for recruiting talented STEM students to the university.
5. Provide a place for critical and creative thinking for students to learn how things are made, becoming fluid in new types of information (e.g., 3d data and models, machine code), and to learn by making.

Usage data: Most of the makerspace users are engineers (69%) and most (58%) want the high-resolution and minimal post-processing of the professional level machine (the UPrint).

Therefore need to :

- Continue a professional-level 3d printing service on Campus 1
- Engage non-engineers more effectively by encouraging Makerspace use by other disciplines, providing more learning experiences, and lowering the barrier to entry for makerspace services.

Rather than replicating are existing model we should expand it:

Campus 2 Makerspace: This new location will provide opportunities for enabling interdisciplinary collaboration and exposing new, non-engineer users to the possibilities of making in new ways:

- A larger space allows hands-on workshops, class visits, and events such as hack nights where students can share projects and learn from their peers.
- Adjacency to most first-year courses provides more opportunities to integrate into curriculum and engage enthusiastic beginners.
- Partnering with North Campus researchers and departments can lead to collaborations with the Communication, Rhetoric and Digital Media Program, the Industrial and Systems Engineering Additive Lab and the College of Education’s Technology, Engineering & Design Education Program.

To lower barriers more affordable and easier-to-use tools such as the MakerBot and consumer focused 3d printers are appropriate. The toolset can combine with rich peer-to-peer learning experiences. We may need multiple machines and more staffing.

This is a large investment and one the libraries should not make alone. Private donors are needed as well as alumni contributions.

Requirements:

- Space required: 600-1000 square feet, occupancy of 20-30
- External ventilation to allow for many 3d printers running simultaneously and safe use of soldering irons and laser cutter
- Sturdy, moveable tables and chairs
- Lockable storage space for supplies and tools
- Desk for staff to check users in, check items in/out

Service and Staffing Model:
Hands-on access to 3d printing - At [Campus 2 makerspace] we'd like to offer students direct access to the machines, so they can learn by doing, by encountering and solving problems, and get more in depth understanding of 3d printing. We can do this by having more 3d printers, and by choosing consumer-focused machines which are more accessible and less costly.

Staff as educator/guide - We'd like to see staff at [Campus 2 makerspace] focus more on the peer educator/guide role. Rather than serve as gatekeepers, they will introduce users to the machines, help solve problems, and connect users with learning resources.

Move away from pay-per-print - Tracking and charging for every 3d print requires a lot of staff time and effort, which could be spent helping users learn. Cost also presents a barrier for new users.

Tap our users' expertise - By allowing users to develop expertise with particular machines, we can then tap them to help their peers in the space and teach workshops.

Involve others - We can expand our offering and encourage interdisciplinary collaboration by recruiting workshop instructors and coordinating events with partners in Design, Education, Industrial Engineering, CRDM and various student groups.

Equipment - 3d printers ($9000-11000), 3d scanners ($2000-3000), Internet of Things/Electronic tools ($1500), Computing ($2000-4000), General tools ($1000) and materials for events and programs ($1000-3000).

Virtual & Augmented Reality Studio
This was planned as a separate project and included 7 desktops for VR development, and equipment including Oculus Rift, HTC VIVE, Magic Leap, Hololens, VR-ready PCs, Development kit hardware, maker-tools. Open for reservations and walk-ins for staff, students 3-10pm. Services include technology consultations, research consultations and background discovery (have people done X with tool Y?) technology lending, play testing and events (hosting capability for classes, groups and demonstrations). Support from student leadership (workshop development, deployment), Peer-to-Peer instruction (student developers and designers offer domain knowledge), networking and incubating collaborators.

Workshops include:

- Virtual Reality Studio orientation
- Intro to 3d scanning
- Getting started with Augmented Reality
- Intro to Spatial Sound in Unreal Engine
- Getting started with VR Illustration
- Getting started with webVR in AFrame
- 360-degree video made easy
- Intro to the Unity Game Engine

Makerspace use data:

Note: The Makerspaces closed at the end of the day on March 13th, 2020 due to the Covid-19 pandemic. Early march counts were low due to the Spring Break holiday (3/9/2020 - 3/13/2020).

Larger Makerspace - 2 (M2)

Registered Users (Unique Users)

	2020	2019	2018	2017	2016
Registered Users	1,655	1,462	954	1,116	906

Door Counts (Total Use)

	2020	2019	2018	2017	2016
Door Counts	28,422	26,506	22,578	21,538	25,454

Equipment Use (Total Use)**

	2020	2019	2018	2017	2016
3D Print	1,603	2,053	1,890	1,276	467
Tools	620	672	322	159	29
Laser Cutter	104	116	151	139	94
3D Design	288	307	144	54	N/A
Sewing	311	258	137	48	12
Electronics	186	213	133	96	11
Soldering	75	82	81	50	10
Milling	5	19	30	14	N/A
3D Scan	0	8	16	4	2
Total	3,088	3,728	2,906	1,724	627

***The FY 2016 totals include only the Spring Semester of 2016.*

Reference Questions* (Total Use)

Equipment	**2020**	**2019**	**2018**
Reference Questions	789	487	167

**Makerspace reference questions were not tracked in FY 2017 and FY 2016.*

Webform Technology Consultation Requests

	2020	2019	2018	2017	2016
3D Printing/3D Scanning	70	47	53	35	16
Arduino/Makey Makey/ Rasberry Pi	17	12	8	6	5
Sewing	7	5	11	2	1
Laser Cutter	4	2	3	3	2
Soldering	0	0	0	2	0
Milling	1	0	0	1	0
Total	99	66	75	49	24

Users by Role (Total Use and Unique Users)

	2020 Total Use	2020 Unique Users	2019 Total Use	2019 Unique Users	2018 Total Use	2018 Unique Users	2017 Total Use	2017 Unique Users	2016 Total Use	2016 Unique Users
Students	8,992	869	10,695	939	8,898	1,390	12,882	906	3,045	269
Staff	154	31	232	32	447	32	1255	28	539	23
Faculty	75	18	235	20	148	54	190	44	56	4
Unidentified	0	0	0	0	79	8	1157	45	92	92
Total	9,221	915	11,162	991	9,572	1,484	15,484	1,023	3,732	388

Student Users by College (Total Use)**

	2020	2019	2018	2017	2016
Engineering	5,335	6,752	5,383	6,137	1,316
Science	1,353	1,535	1,079	776	200
Humanities and Social Sciences	551	557	737	794	231
Agriculture and Life Sciences	420	469	364	350	170
University College	280	385	382	577	247
Design	208	320	197	426	191
Management	283	236	196	222	165
Natural Resources	128	137	120	81	17
Education	168	130	154	25	15
Textiles	216	119	224	366	107
Non-Degree Studies	49	45	60	22	9
Total	8,991	10,685	8,896	9,776	2,668

***2016 Unique User totals only include data from the Spring Semester 2016*

Student Users by Ethnic Group*(Unique Users)

	2020	2019	2018
White	559	590	880
Asian	132	165	253
Not Specified	49	69	69
African American	64	60	81
Hispanic/Latino	54	44	68
American Indian / Alaskan Native / Native Hawaiian / Other Pacific Island	14	12	3
N/A	0	1	36

Total	869	941	1,390

**Makerspace users' ethnic group was not tracked in FY 2017 and FY 2016.*

Student Users by Gender* (Unique Users)

	2020	**2019**	**2018**
Male	528	616	887
Female	342	322	488
N/A	0	1	15
Total	869	939	1,390

**Makerspace users' gender was not tracked in FY 2017 and FY 2016.*

Use and Users
M1

Registered Users (Unique Users)

	2020	2019	2018	2017	2016
Registered Users	152	195	252	257	229

3D Prints (Total Use)

	2020	2019	2018	2017	2016
3D Prints	495	1,840	2,234	1,719	1,286

M1 and M2 Technology Lending (Total Use)

	2020	2019	2018	2017	2016
Checkouts for Makerspace Technology (excluding renewals)	1,762	2,844	3,251	1,552	471

Item Group	Item	2020	2019	2018	2017	2016
3D Scanner	Matter And Form 3D Scanner	4	15	12	3	n/a
3D Scanner	Structure Scanner	12	16	44	35	43
3D Scanner	Structure Scanner iPad	18	22	49	52	49
3D Scanner	Xbox One Kinect For Pc	1	4	9	2	0
Adafruit	Flora Wearable Electronic Platform Kit	0	0	0	6	3
Adafruit	Mini Thermal Receipt Printer	0	0	0	1	1
Analog Discovery	Analog Discovery 2	188	162	141	95	n/a
Apple 8 pin to USB Cable	Apple 8 Pin To Usb Cable	0	0	6	0	0
Apple iPod touch	iPod Touch 32Gb	0	0	6	0	0
Apple Laptop Power Adapter	Apple 60W Magsafe 2 Adapter	10	86	210	1193	288
Arduino	Arduino 101	0	0	0	1	n/a
Arduino	Arduino Inventor Kit	158	20	300	1	n/a
Arduino	Inventor Kit 4.0	0	201	n/a	n/a	n/a
Arduino	Makerspace Inventor Kit 4.0	17	10	n/a	n/a	n/a
Arduino	Arduino Inventor Kit Yun	0	0	0	1	3
Arduino	Arduino Uno	0	0	0	0	3
Charmed Labs	Pixy Smart Vision Sensor	0	0	0	0	1
Circuit Playground Developer Edition	Circuit playground	0	1	1	16	n/a
Digital Multimeter	Digital Multimeter	0	0	0	1	n/a
Intel Galileo Mini Inventor's Kit	Intel Galileo Kit	0	0	0	27	28
Internet of Things Starter Kit	Internet Of Things Starter Kit	13	43	67	0	n/a
iRobot Create 2	iRobot	0	11	6	0	0
Kano Kit	Kano Kit	0	4	5	0	1
LilyPad Design Kit	Lilypad Design Kit	0	0	3	9	15
littleBits Kits	Korg Synth Kit	4	9	7	n/a	n/a
littleBits Kits	Littlebits Premium Kit	5	4	19	0	0
LSS Staff Lending	Sphero Power Pack	3	0	1	n/a	n/a
M3D Micro 3D Printer	Micro 3D Printer	0	1	0	0	0
Magnetic Strip Card Reader	Magnetic Strip Card Reader	0	0	0	1	n/a
Book	Make Games with Python	0	1	X	n/a	n/a
Makerspace Lockers	Locker	83	72	94	9	n/a

Item Group	Item	2020	2019	2018	2017	2016
Makerspace MacBook Air	Makerspace Macbook Air	1026	1801	1574	n/a	n/a
Makerspace Project Box	Makerspace Project Box	2	10	7	n/a	n/a
Makey Makey - standard kit	Makey Makey	24	19	30	0	0
Moog Werkstatt Kit	Moog Werkstatt Kit	16	21	29	0	0
Muse Brain Sensing		14				
Headband	Muse Brain Sensing Headband		30	42	0	0
NeuroSky	Mindwave Mobile	6	15	32	0	8
Othermill Toolkit	Othermill Toolkit	4	15	16	16	0
Ototo Musical Inventor's Kit	Ototo Kit	0	0	0	0	3
Ototo Musical Inventor's Kit	Ototo Music Kit	0	0	12	9	6
Particle	Internet Button	0	0	0	0	1
Physical Computing Starter		4				
Kit with Circuit Playground	Physical Computing Starter Kit		17	n/a	n/a	n/a
Pi Camera Board (NoIR)	Pi Camera Board (NoIR)	0	0	0	1	n/a
Pro Trinket	Pro Trinket	0	0	1	1	0
PunchThrough	Lightblue Bean	0	0	3	0	4
PunchThrough	Lightblue Bean+ Starter Kit	1	4	15	n/a	n/a
Raspberry Pi	Raspberry Pi	87	0	0	1	2
Raspberry Pi	Raspberry Pi Display Kit	21	62	n/a	n/a	n/a
Raspberry Pi	Raspberry Pi Camera Board	0	0	0	1	5
Raspberry Pi	Raspberry Pi Kit	0	142	382	68	0
SDR Active Learning Module	Adalm-Pluto	0	1	n/a	n/a	n/a
Software Defined Radio Kit	Rtl Sdr Blog	29	6	n/a	n/a	n/a
Solar Electronics Kit	Solar Electronics Kit	0	0	0	2	0
Sparkfun Peripherals	Photon Kit	0	0	0	0	6
SPHERO	Sphero Bolt	12	2	n/a	n/a	n/a
SPHERO	Sphero Sprk	0	17	85	0	0
Sprarkfun RFID Starter Kit	Sprarkfun RFID Starter Kit	0	0	1	0	n/a
Teensy	Teensy	0	0	0	0	1
USB Drive	Usb Drive	0	0	38	0	0
USB Power Block	Ipad Usb Power Adapter	0	0	4	0	0

Instruction

Instruction Type	2020 (7/1/2019-12/31/2019	2020 (1/1/2020-3/13/2020)
Course-based Instruction-Sessions	44	
Course-based Instruction-Audience Size	1009	
Workshops-Sessions	74	
Workshops-Audience Size	691	
Other Teaching and Outreach-Sessions	8	
Other Teaching and Outreach-Audience Size	181	
Total Program Type	**126**	
Total Audience Size	**1,881**	

Course-Based Instruction Courses

Course Name	Number of Session 7/1/2019-12/31/2019	Number of Sessions (1/1/2020-3/13/2020)
Academic Writing and Research	12	
Introduction to University Education I	6	
Introduction to Engineering & Problem Solving	4	
Introduction to Women's and Gender Studies	3	
Electrical and Computer Engineering Senior Design Project I	3	
Technology in the Arts	2	
Multimedia Production and Digital Culture	2	
Foreign Language	2	
Technology Tools for Science Teaching	2	
Poultry and People	1	
Writing in the Rhetorical Tradition	1	
Public Speaking	1	
Disease Outbreaks	1	
Emerging Issues in Women's and Gender Studies	1	
Communication for Business and Management	1	
Design History for Engineers and Scientists	1	
Computer Documentation Design	1	
Total	**44**	

Workshop Titles

Workshop Title	Number of Session 7/1/2019-12/31/2019	Number of Sessions (1/1/2020-3/13/2020)
Makerspace Orientation	38	
Getting Started with 3D Printing	4	
Getting Started with 3D Design	4	
Getting Started with Digital Sculpting	3	
Getting Started with the Raspberry Pi: Building and Controlling Beginner Projects	3	
Getting Started with Screen Printing	3	
Sewing Basics I: Sew Fun	3	
Getting Started with eTextiles	2	
Getting Started with the Internet of Things	2	
Prototyping Electronics with Arduino	2	
Learn to Sew: Sensory Activity Blankets	1	
Build and Upgrade Your Own PC	1	
Getting Started with Simple Circuits and Soldering	1	
Getting Started with Arduino	1	
Getting Started with Bookbinding	1	
Screen Printing with Conductive Ink	1	
Getting Started with Circuits and Soldering	1	
Getting Started with Autodesk Fusion 360	1	
Getting Started with Digital Embroidery	1	
Say It: A Zine Making Workshop	1	
Total		

Other Teaching and Outreach

Outreach Organization	Number of Session 7/1/2019-12/31/2019	Number of Sessions (1/1/2020-3/13/2020)
Women in Engineering ESCape Camp	1	
Southeast Regional High School	1	
Textiles Engineering Student Society	1	
Animal Health Hackathon	1	
BMES	1	
Engineering Village	1	
Center for Family and Community Engagement	1	
FUTURE INGENIEROS	1	
Total	**8**	

Instruction

Instruction Type	2019	2018	2017	2016	Total
Course-based Instruction-Sessions	41	64	47	29	181
Course-based Instruction-Audience Size	1,020	1,354	980	554	3,908
Workshops-Sessions	146	113	106	152	517
Workshops-Audience Size	996	972	1,167	1,620	4,755
Other Teaching and Outreach-Sessions	20	26	19	7	72
Other Teaching and Outreach-Audience Size	335	1,616	2,228	77	4,256
Total Program Type	**207**	**203**	**172**	**188**	**770**
Total Audience Size	**2,351**	**3,942**	**4,375**	**2,251**	**12,919**

Course-Based Instruction Courses

Course Name	Number of Sessions
Academic Writing and Research	15
Technology in the Arts	14
Mobile Communication	11
Electrical and Computer Engineering Senior Design Project I	9
Introduction to University Education I	8
Multimedia Production and Digital Culture	7
Mobile Media and Communication	7
Honors Seminar: Reading Machines	6
Honors Special Topics-Science, Technology, Society-H&SS Perspective	5
Studies in Rhetoric and Digital Media	5
Foreign Language	5
Science Fiction	4
Internet and Society	4
Poultry and People	3
Interdisciplinary Studies in English	3
Interdisciplinary Perspectives Special Topics: Big Data	3
Advanced Three-Dimensional Fibers Forms and Structures	3
Introduction to University Education II	3
Biomaterials Characterization	3
Science Fiction and Steampunk	3
Information Technology Capstone	3
Communication and Technology	3
Special Problems in Math Teaching	2
Women and Literature	2
Special Studies in Textile Engineering and Science	2
Woven Textile Design Studio I	2
New Media & Contemporary Art	2
Game Studies	2
Mechanical and Aerospace Engineering	2
Experiencing Information	1
Communication for Engineering and Technology	1
Leadership Development for the University Ambassadors	1
Fashion Design 2	1
Special Topics in Design	1
Communication Rhetoric and Digital Media/Interdisciplinary Studies in English	1
Fashion Product Development	1
Composition Theory & Research	1
Advanced Graphic Design Studio	1

Advanced Architectural Design	1
Special Topics in Communication, Rhetoric, and Digital Media	1
Horticultural Science	1
Special Topics in Science, Technology, and Society	1
Organic Chemistry	1
Technologies and Pedagogies in the Communication Arts	1
Biomedical Engineering design and Manufacturing II	1
History of Industrial Design	1
Engineering Entrepreneurship and New Product Development I	1
Learning Theories in STEM	1
Intro to Science, Technology, and Society	1
Total	**181**

Workshop Titles

Workshop Title	Number of Sessions
Makerspace Orientation	283
Getting Started with 3D Printing	22
Getting Started with 3D Scanning	21
3D Scanning Studio Orientation	20
Sewing Basics I: Sew Fun	19
Getting Started with 3D Design	15
Getting Started with Arduino	14
Getting Started with eTextiles	13
Getting Started with the Internet of Things	11
Getting Started with Photogrammetry	8
Getting Started with the Raspberry Pi: Building and Controlling Beginner Projects	7
Getting Started with Digital Embroidery	7
Coding for Wearables I	6
CAD 101: Intro to Digital Fabrication with Autodesk Fusion 360	6
Open in Order to Build: Developing Open Projects in Arduino	3
Making Molecules with 3D Printing	3
Create Custom Laser-Cut Business Cards	3
Prototyping Electronics with Arduino	3
Makerspace Orientation for FEDD 3D Printing	3
Getting Started with Circuits and Soldering	3
Future Wearables	2
Othermill Stamp-Milling Workshop	2
The Power of Open: 3D Printing & Design	2
Making in the Classroom, Making in the Lab	2
Developing 3D Printed Projects	2
Design Thinking Workshop	2
Intermediate CAD & 3D Printing: Digital Design Best Practices with Autodesk Fusion 360	2
NoCoMicro Thingamajigs: A Hands-on Workshop with the Circuit Playground Express	2
Getting Started with Digital Sculpting	2
Bookmaking Workshop	1
The Art of Making Data: Quantifying Attitudes and Emotions	1
Getting Started with Creative Coding	1
Engineering Village Orientation & 3D Printing	1
DSiP Critical Making Workshop	1
Getting Started with SLA 3D Printing	1
Creative Coding with Sensor Data	1
Extending the functionality of the Moog Werkstatt using electronic circuits	1
Developing Arduino Projects	1
Critical Making for Sustainability	1
The Art of Making Data: Quantifying Touch	1

Get Rolling With Sphero: Code and Create	1
Electronic Embroidery	1
Intro to Google Cardboard	1
Open in Order to Create: Developing Open 3D Printed Projects	1
Make & play w/ Makey Makey	1
Possibilities with Raspberry Pi	1
Make-A-Thon Workshop	1
Scientific Computing with Raspberry Pi	1
Makerspace Beta Workshop Series	1
STEM Education and Critical Thinking with the Raspberry Pi	1
Code+Art Hackathon with Processing and Arduino!	1
The Art of Making Data: Quantifying Sound	1
CAD 101: Digital Design Best Practices with Autodesk Fusion 360	1
The Future of Making Things in the Classroom	1
Next-Level CAD	1
TRLN SparkFun workshop	1
Next-Level CAD: Advanced CAD & 3D Scanning Best Practices	1
Design and Printing of 3D Ceramics: Hands-On Workshop	1
Total	**517**

Other Teaching and Outreach

Outreach Organization	**Number of Sessions**
Moogfest & Moog Music	7
EcoVillage	3
Emerging Scholars Academy (Pre-College)	3
TH!NK program	3
Music Technology Summer Camp	2
Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) Center	2
Make-a-thon	2
Minority Engineering Programs	2
Engineering Village	2
Graduate Student Orientation	2
GTI Technical Communication Institute	2
STEM BUILD	2
TES (Textile Engineering Society)	2
University Scholars Program	2
WISE & Engineering Village	2
Arts Village	2
Biomedical Engineering Club	1
Biotechnology + NC School for the Deaf	1
BME: Rehabilitative Engineering and Regenerative Medicine Groups	1
Cary Academy	1
CVM Open House	1
DELTA Instructional Design Interest Group	1
Entrepalooza	1
Explore Teknikio in advance of Deren Guler's workshop.	1
Girls Inspiring Real Leadership and Sisterhood (G.I.R.L.S.) camp	1
Global Training Initiative	1
Henrico County Public Schools	1
IDIG/DELTA (Instructional Design Interest Group?)	1
4H Club	1
Friends of the Library	1
TRIO Upward Bound	1
Upward Bound (TRIO)	1
Central University	1
Office of Faculty Development	1
Olli	1
Peer Scholars Program	1
Prospective CRDM grad students	1
Prospective students - Masters program in Communications Dept.	1
SciBridge	1
Sisterhood Dinner	1
Staff Women's Network	1

Summer START	1
Technical Writing Certificate Program	1
Technology Learning Services	1
The Carrack	1
Wake STEM Early College High School	1
Wolfpack Welcome Week	1
Women in Engineering	1
Total	**72**

Appendix 7 Analytical process for all data collected

- I read all texts for initial thoughts on codes and categories (whether interview transcript or observation).
- I read through all texts to flag up CHAT based Tensions and Contradictions to consider more in-depth later.
- I read through for *Categories* not covered already.
- I read through for how the Library service and learning resources were being developed to expand services, overcome system tensions, and make practical moves to create new service aims and objectives.
- I read through for how the *Categories* could be fitted into *Themes* for wider CHAT based analysis in terms of the dialectics between the case study makerspace service and wider maker culture.
- I made my initial *Template Analysis* from the first interview from each participant type (Staff, Academics, Students), which then developed during the research project's further data analysis.
- Further readings were carried out as part of the interpretive process as insights were established and developed and links were made to the dialectics of my CHAT framework. This was a circular hermeneutic process looking to and fro from parts to the whole of the data and applying the interpretive dialectic logic of CHAT where appropriate.

Appendix 8 Overview of identified risks and actions

Identified Risk	**Risk Type**	**Action**
Dignity and freedom of participants	Psychological, Social, Legal	- Accurate participant information was given - Appropriate consent forms were used - Participants could withdraw at any point
Privacy of all participants/ confidentiality of data	Psychological, Social, Legal	- All data was member checked for accuracy - All data was cloud-stored through Oxford Brookes University with double password protection - Consent was obtained for data to be used in future publications - Anonymity will be given to all participants in data and published research

Awareness of vulnerable groups	Psychological, Social, Legal, economic	- When observing inclusivity of makerspace I ensured less confident users were fully respected and opinions valued - I was sensitive to potential cultural differences and relational tensions between individuals and/or groups - Time was spent with less confident/ non-typical makerspace users to explore issues around inclusivity

Respecting the values and motives of other	Psychological, Social	Respect for people's values was a fundamental component of my conceptual framework, including: 'Relational Agency': Actively trying to understand the motivations and moral perspectives of other professionals. 'Relational Expertise': Through understanding and respecting the standpoint of others including those with less power, collective shared goals can be more effectively achieved (Edwards, 2017). These concepts frame a practical/professional approach for me, as well as a theoretical framework for understanding aspects of my research.

Scientific Integrity	Psychological, Social	As with the previous research I have undertaken, I ensured the research was carried out with honesty, impartiality and a willingness to accept fallibility. This is in keeping with the research standards in the Library and Information Science literature and wider Education community (BERA, 2018) as well as Oxford Brookes own standards (Brookes, 2016). Outcomes included: -a detailed up to date literature review -in-depth data collection/verification and analysis -the intention to publish research outcomes in high quality peer reviewed journals.

Appendix 9 Makerspace photos

Image 1 – Photo of the main case study makerspace

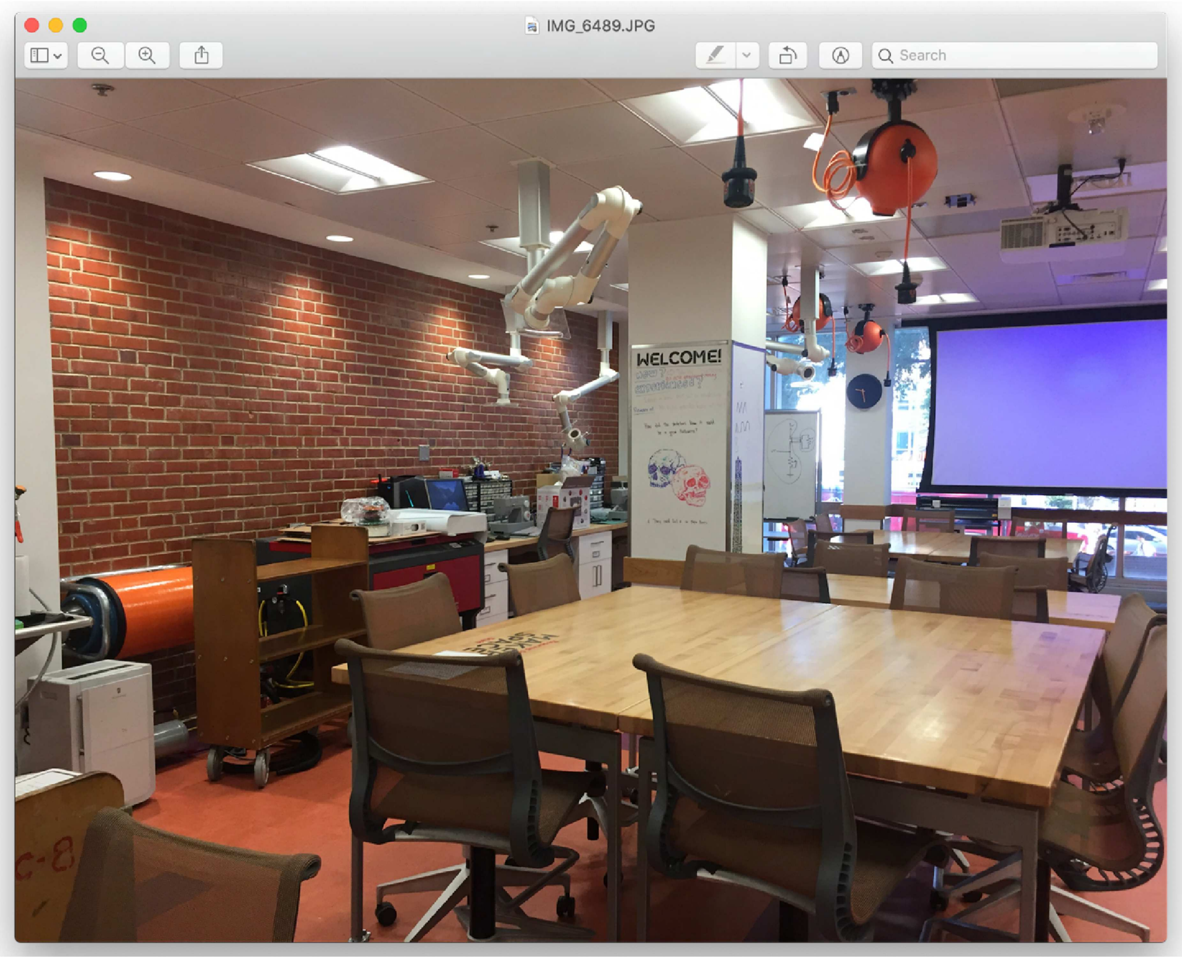

Image 2 – Equipment to borrow

Image 3 – Laser cutter

Image 4 – Electronics equipment including switches, sensors, jumper wires and speakers

Image 5 – Sewing equipment and materials

Image 6 – Tools and protective equipment

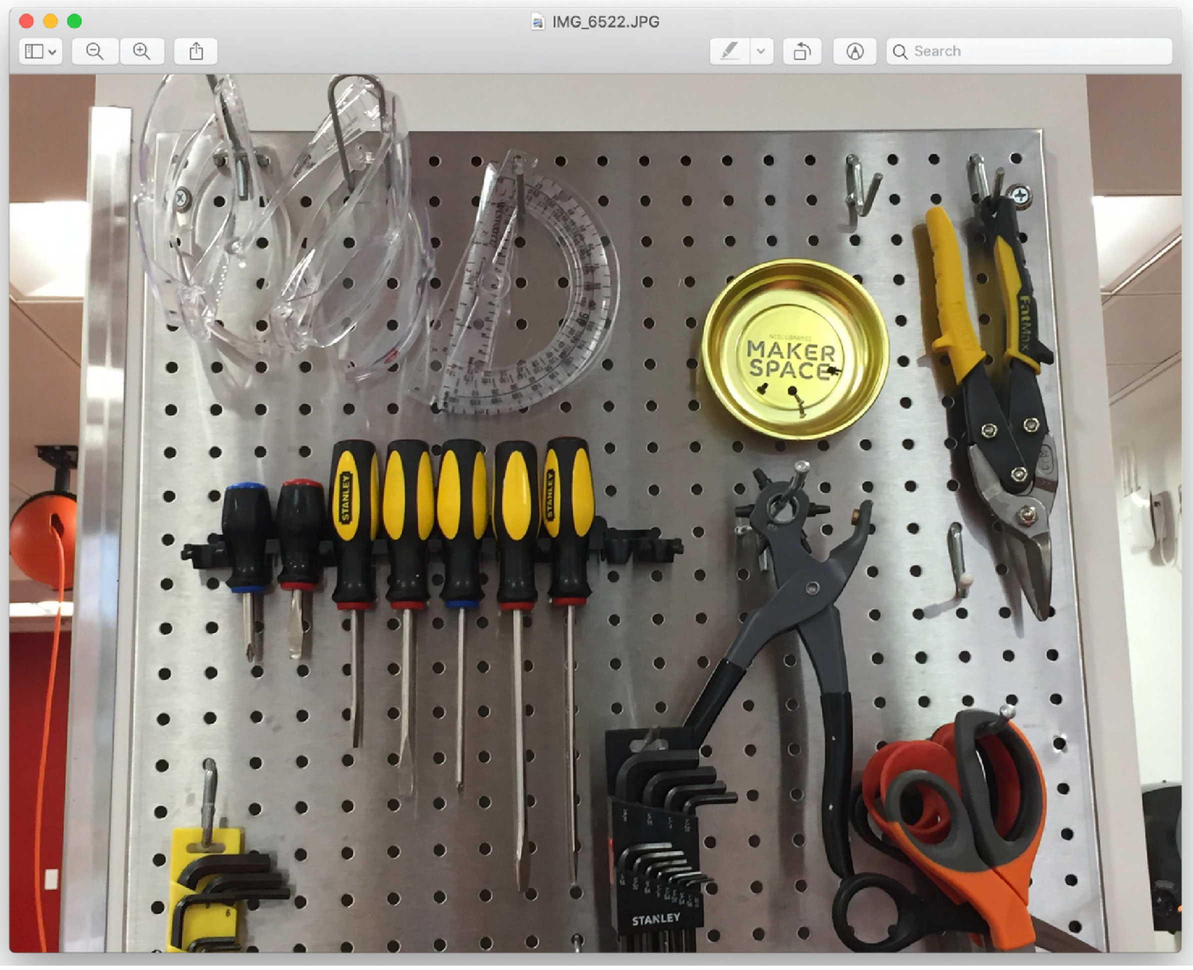

Image 7 – 3D Printers

Image 8 – Model of our solar system

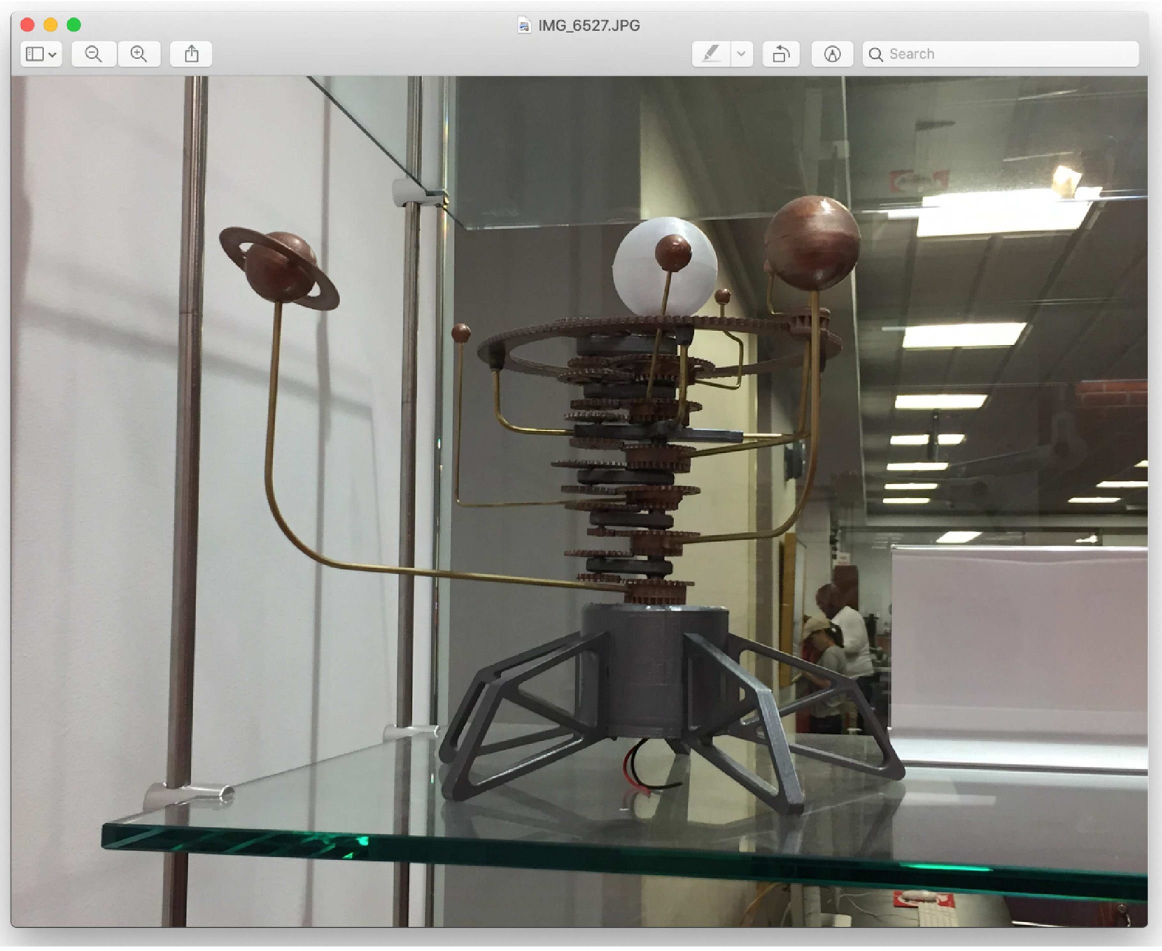

Image 9 – Maker magazines and books

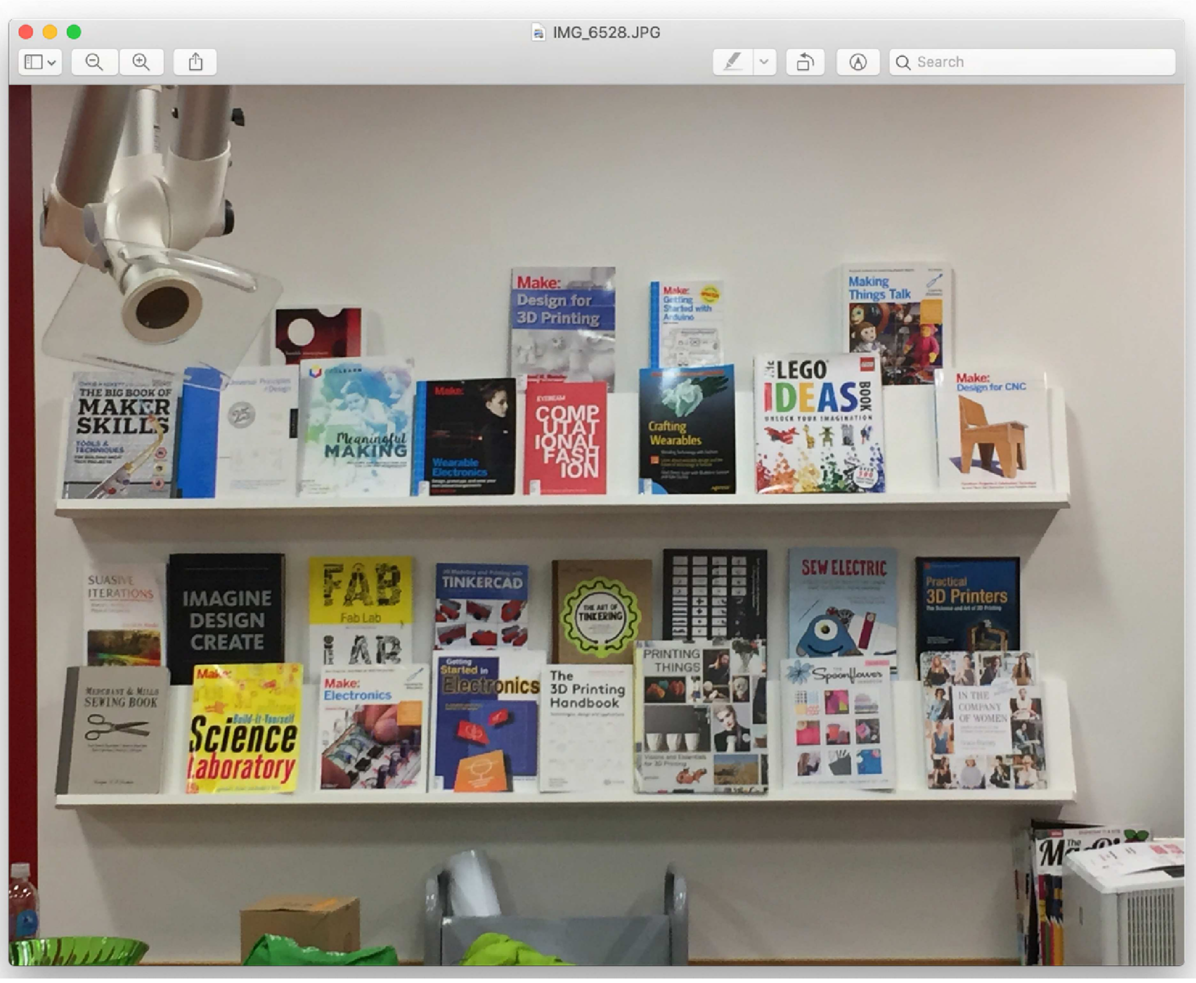

Image 10 – Molecular puzzle

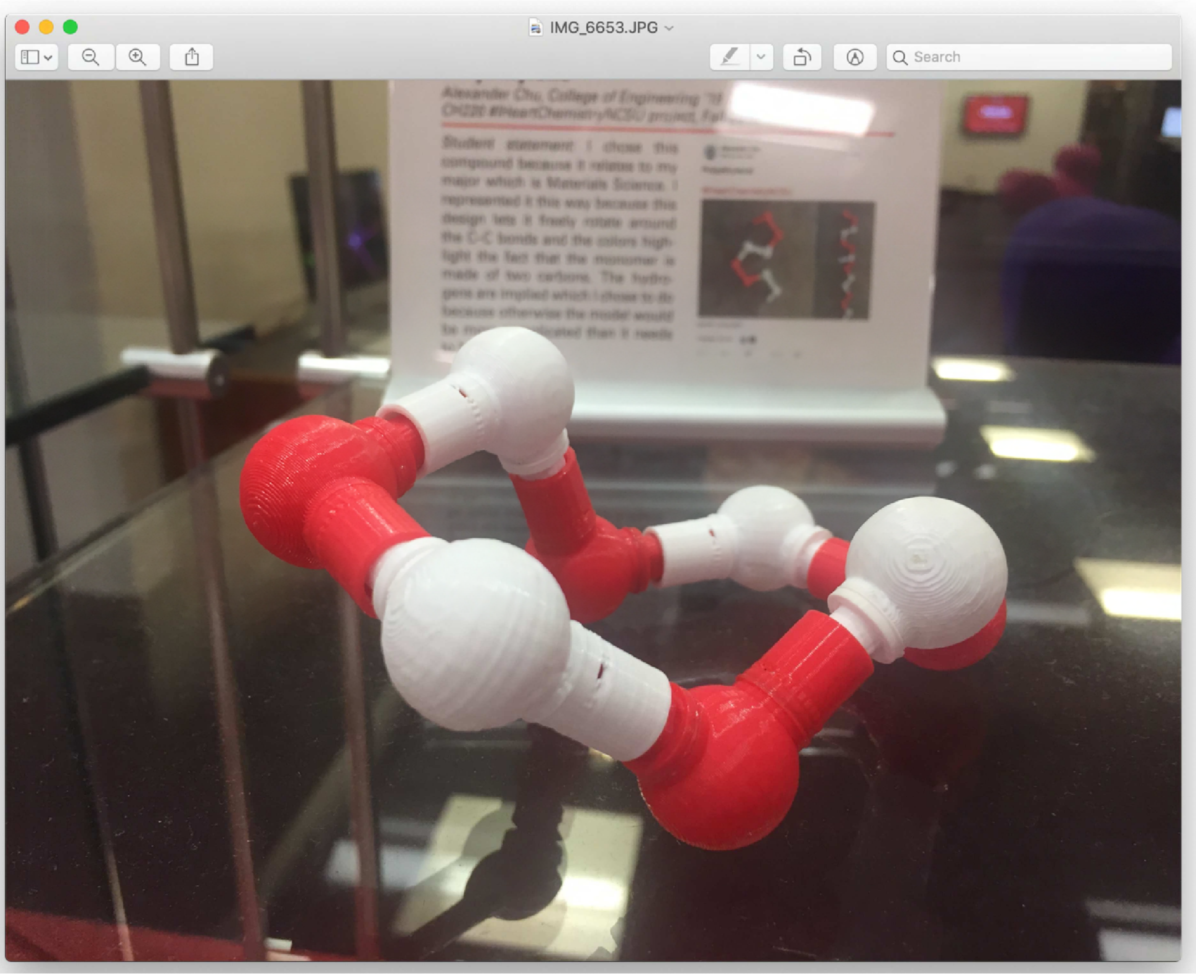

Image 11 – Clay tablet with cuneiform

Description card on display for above clay tablet with cuneiform
(by Erica, female engineering student, age 20)

‘This handmade clay tablet is inscribed with cuneiform translation of the text: “It is their very ordinariness that makes them invisible.” It was part of a display of several historical descriptive mediums, including Egyptian hieratic script brush-writing on papyrus, a Roman wax tablet, a parchment sample inscribed with a quill, hand-made paper, letterpress with handset type, an ebook version, and QR code.’