(Un)settling differences:

Re-conceptualisations of technologically-mediated interdisciplinary research in Higher Education



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ABSTRACT

Increasing prominence continues to be given to interdisciplinary collaboration as a means of addressing challenges within academia, the private sector and government (Frodeman, Klein and Pacheco, 2017). In parallel, new and innovative technologies have been positioned as mediating artefacts in these endeavours (Mulcahy, 2013). Yet there is a need for enhanced understandings of these technologically-mediated interdisciplinary practices in order to acknowledge the depth and complexities of the phenomena, attending to the socio-materiality of humans *and* non-humans, to (un)settle the 'grand narratives' of interdisciplinarity and technology, and 'to interrogate the unity of interdisciplinarity' (Barry and Born, 2013: 5).

This research focusses on generating deeper and more nuanced insights into how interdisciplinary research happens in projects building new technologies in Higher Education. The complexities inherent in studying interdisciplinary concepts, researchers and technologies necessitates a more critical approach which can account for the heterogeneity of practices, multiplicity of participants and ontologies, and constantly shifting relations (Mol, 2002; Barry, Born and Weszkalnys, 2008; Donaldson, Ward and Bradley, 2010). This study therefore adopts a qualitative design which conceptually, theoretically and methodologically draws from Science and Technology Studies (STS) (Sismondo, 2010), and more specifically, from Actor-Network Theory (ANT) (Law, 2004; Latour, 2005; Fenwick and Edwards, 2018). The core research question is: How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?

Through a praxiographic, collective case study of three interdisciplinary research projects (a Medical Robotics project, a Digital Humanities initiative and an Energy project) based at a University in the USA with a strong socio-historical culture of innovation, this study 'follows the actors' through the unfolding processes of interdisciplinary teams moving from research questions to emerging technological outcomes in order to investigate enactments of interdisciplinarity (Latour and Woolgar, 1979; Callon, 1986; Thompson and Rimpiläinen, 2012). Situated, distributed interdisciplinarities are found to be mediated and embodied by technologies-in-development, often irreducible to their antecedent parts, and 'made of' relational tensions. These findings bring forward the multiplicities of interdisciplinarity *in practice*, moving away from 'conventional' framings of interdisciplinarity as synthesis or boundary-crossing. This study also reflects upon how drawing from ANT has productively 'opened up' these multiplicities, moving from (inter)disciplinary perspectives to (inter)disciplinary realities, and illuminating how non-humans also participate in research practices in Higher Education.

This research contributes rich empirical accounts of interdisciplinarity and technological development to the existing body of knowledge around the phenomena, and advances theoretical and methodological applications of ANT in Education (Sørensen, 2009; Fenwick and Edwards, 2010, 2018). The findings hold broad implications for substantive promotion of enhanced conceptual, socio-material understandings of technologically-mediated interdisciplinary practices.

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I dedicate this thesis to my parents, Heather and Brian

to Grandad and Robert – we miss you

and to Grampa and little Nan – wish you could see this

DECLARATION

I declare that this thesis is a presentation of my original research work and has not previously been submitted for a degree from any other university. To the best of my knowledge, this thesis does not contain any material previously published or written by another person except where duly acknowledged in the text.

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LIST OF ABBREVIATIONS

ANT Actor-Network Theory

CS1 Case study 1 (Medical Robotics)

CS2 Case study 2 (Digital Humanities)

CS3 Case study 3 (Energy)

HE Higher Education

ICT Information and Communication technology

IDR Interdisciplinary research

STS Science and Technology Studies

CHAPTER 1: INTRODUCTION

1.1 Research Rationale

Increasing prominence continues to be given to interdisciplinary collaboration as a fundamental means of addressing challenges within academia, industry and government (Frodeman, Klein and Pacheco, 2017). In particular, there is a growing call for interdisciplinary research to respond to complex, 'real-world' problems, and help produce 'responsible' research. Simultaneously, emerging technologies have been positioned as mediating artefacts in interdisciplinary research endeavours (Mulcahy, 2013). Developing technologies is particularly an important feature of many interdisciplinary projects designed to solve social and technical problems. Despite a growing body of knowledge around interdisciplinarity, as well as on the technological mediation of scholarship and the ways that technologies can support interdisciplinarity, there are remarkably few studies which conceptually and critically acknowledge the depth and complexities of the phenomena. The positioning of technology and conceptualisation of interdisciplinarity in most existing literature is thus a weakness of current research into technologically-mediated interdisciplinary practices. This study aims to address this in order to better acknowledge the complexities involved in understanding how technologically-mediated interdisciplinarity happens.

Although there are many ways that technology features in research, this study specifically focusses on generating deeper and more nuanced insights into interdisciplinarity in research projects building new technologies in Higher Education. The development of technologies during interdisciplinary research is a particular type of mediation, and thus a 'part' of what I term technologically-mediated interdisciplinarity. Technologies-in-development are especially a focus through which what happens in technologically-mediated interdisciplinarity becomes visible (see section 2.1.1). As such this thesis contributes to enhanced conceptual, socio-material understandings in the area, providing rich empirical accounts of interdisciplinarity and technological development 'in practice'.

The work also advances theoretical and methodological applications of Actor-Network Theory (ANT) in the field of Education, directly addressing the vital need for a deeper understanding of relationships between technological development and interdisciplinary research within the academy.

Four, inter-related critiques form the rationale for this thesis. First, despite a small number of studies moving towards more sophisticated theoretical framings of technologically-mediated interdisciplinarity, such as those taking a socially shaped approach (e.g. Fry and Schroeder, 2010), there are as yet only indications of how disciplines and technologies shape each other. Much research into the technological mediation of (interdisciplinary) scholarship takes the position, deliberately or otherwise, of technological determinism (e.g. Hermann, Rummel and Spada, 1998). Technology is under-theorised, particularly within the field of Education (Oliver, 2011, 2013), and 'more research is required that moves away from a means-end thinking about how best to harness the presumed inherent educational potential of… technology, and instead focuses on the socially contested and socially shaped nature of technology' (Selwyn, 2010: 66). We need to diverge from the 'effects of' technology 'on' interdisciplinary research, to how they can be understood in relational ways. Studies 'fail to acknowledge the negotiation of practices and co-evolution of practices and technology that are involved', note Haythornthwaite et al. (2006: 144). Investigation into the construction of technology *through* scholarly research is under-developed, and related work with regards to interdisciplinary scholarship is even less so. This is not solely about facilitation, communication or orchestration, but about how innovative technologies might mediate interdisciplinarity in fundamental ways.

Second, and in parallel with the first critique, more critical work investigating interdisciplinary research needs to be carried out. Klein (1990: 38) describes an 'undeniable momentum' towards interdisciplinarity in the latter part of the 20th century, and the phenomenon is often presented as an unquestioned 'good', and as 'an innovation

in knowledge production' (Frodeman, 2010: xxix). The current preoccupation with interdisciplinarity, this 'hype' (Jacobs, 2009), and the increasingly high stakes with which it is associated, warrant urgent, advanced conceptual and empirical investigations.[1] There is a need to move away from these 'grand narratives', and as such this study responds to the call by Barry, Born and Weszkalnys (2008: 42) to 'raise the prospect of a re-evaluation of interdisciplinarity'. I challenge many of the existing conceptualisations and definitions of interdisciplinarity in Higher Education, positioned as integration and synthesis across disciplinary silos, as too simplistic and reductionist. 'The idea that research should become more interdisciplinary has become commonplace… yet the term tends to obscure as much as illuminate the diverse practices gathered under its rubric', point out Barry and Born (2013: i). Indeed, Donaldson, Ward and Bradley (2010: 1534) argue that the 'traditional' discourse around interdisciplinarity as synthesis does not, on the whole, acknowledge the 'mess' inherent in practice, and Graff (2015) makes it clear that the 'framing' on interdisciplinarity is in dire need of greater conceptual clarity.

Third, and relatedly, most conceptualisations of interdisciplinarity and interdisciplinary research in Higher Education are based solely on human interactions and their disciplinary affiliations. 'A focus on interdisciplinary researchers can cause us to miss the things they work with… The objects around and through which interdisciplinary research is conducted are side-lined by the conventional view that focuses on languages, motivations, and the primacy of disciplinary discourse', argue Donaldson, Ward and Bradley (2010: 1533 – 1534). There is a need to attend to the roles which non-humans, for example technologies, play in these practices, moving away from the traditionally humanist explanations and 'tropes' of interdisciplinarity (e.g. Carr, Loucks and Blöschl, 2018). Indeed, 'education remains almost inherently humancentric by definition', explain Fenwick and Edwards (2018: 15), continuing that '…yet socio-material studies suggest the

[1] Interdisciplinarity can create a sense of incoherence, and thus further investigation into interdisciplinarity is a pressing priority for certain areas, for example, technology-enhanced learning (TEL) (Selwyn, 2013; Scanlon and Conole, 2018).

need for us to at least problematise such a focus, if we want to do worthwhile educational work'. This is not to say that all inquiries have been unsuccessful in this regard, however, and a small number of empirical studies of interdisciplinarity confound these standard narratives. Indeed, this thesis will outline some of this research which frames interdisciplinarity as material practice, and explain how this current study builds upon the existing work. ANT can attend to the array of humans *and* non-humans which participate in research and technological development in interdisciplinary projects in Higher Education, privileging neither the technology, nor the human (e.g. Law, 2004; Latour, 2005; Fenwick and Edwards, 2018).

Finally, and building on the previous three critiques, very few studies empirically look at interdisciplinarity 'in practice'. Critical reflection on the phenomenon and its role in addressing complex problems, particularly within technology projects, is constrained by a predominance of 'conventional' descriptions of interdisciplinarity which are seldom examined or tested against actual practice (e.g. Kockelmans, 1979). Interdisciplinarity 'as it happens' is scarcely interrogated, and 'there is little research on how interdisciplinary projects actually work - and do not work - in practice', note Callard, Fitzgerald and Woods (2015: 1). This study responds to the 'paucity of empirical studies of how interdisciplinarity unfolds in practice' (Barry and Born, 2013: 2), exploring how interdisciplinarity (including processes of knowledge co-production, interdisciplinary methodologies and collaborative practices, for example) and technological development happen, as they happen.

1.2 Research Context and Objectives

Novel theoretical and methodological development is necessary to advance understandings of, and generate new insights into, how interdisciplinarity happens in technology projects in Higher Education. The complexities inherent in studying interdisciplinary concepts, researchers and technologies necessitate a more critical approach which can account for the heterogeneity of practices, multiplicity of participants,

and constantly shifting relations. Much 'work on interdisciplinarity misses or overlooks the complexity of interdisciplinarity politics and the… heterogeneity of interdisciplinary practices…' argue Frickel, Albert and Prainsack (2017: 6). This thesis thus reframes the 'conventional' discourse on technologically-mediated interdisciplinarity, to matters concerning the socio-material practices of interdisciplinarity.[2] The study therefore adopts a qualitative, ethnographic design which draws from Science and Technology Studies (STS) (Sismondo, 2010), and more specifically from Actor-Network Theory (ANT) (Law, 2004; Latour, 2005; Fenwick and Edwards, 2018).[3] 'The knowledge practices and political practices of education provide good grounds for STS and ANT research' suggest Gorur et al. (2019: 11), and I demonstrate throughout this thesis how I engage with Actor-Network Theory (ANT),[4] particularly the principles of translation and heterogeneous networks, as a conceptual, theoretical and methodological practice, offering ways to critically examine and address all four of the above critiques.

'ANT offers numerous insights for those pursuing [studies of] interdisciplinar[ity]', notes McMurtry (2013: 93), yet 'it has been hard to find many published works engaging STS-style ethnographic approach[es], let alone studies on interdisciplinary working' comments Rimpiläinen (2012: 37), reflecting on a report from Mayer, Wöhrer and Stöckelová (2008). Indeed, ANT can attune well to technologically-mediated interdisciplinary practice as the object of study. The 'framing' offers the potential to delineate tensions which exist in current research in the area, allowing a move away from 'traditional' (inter)disciplinary perspectives towards (inter)disciplinary realities, from worldviews to worlds, in order to generate more critical conceptual understandings which take into account the material participations of interdisciplinarity. It is commonplace to assume that interdisciplinarity is about 'managing diverse perspectives or even reconciling them.

[2] Where 'technologically-mediated interdisciplinarity' *is* (a form of) 'socio-material practice'.
[3] Law (2009: 141) characterises ANT as 'a disparate family of… tools, sensibilities and methods of analysis that treat everything… as a continuously generated effect of the webs of relations within which they are located'. This will be more fully introduced in chapters 2 and 3.
[4] See chapters 3 and 7 for discussion around the narrative 'style' of this thesis.

[However] the recent ANT switch to understand educational practices as *multiple simultaneous ontologies* opens a rich new approach [to studying and understanding the phenomena]', explain Fenwick and Edwards (2010: 159). ANT sensibilities help me attend to, and interfere with, processes of (un)settling differently enacted realities in technologically-mediated interdisciplinary research projects.

Exploring how heterogeneous research teams (both human and non-human) enact interdisciplinarity 'in-the-making' (Mattila, 2005: 16), thereby attending to the 'plasma' of interdisciplinarity (Latour, 2012: 93), this study makes visible technologically-mediated interdisciplinarity in practice. The study 'follows the actors' (Callon and Law, 1982: 284), moment-to-moment, through the unfolding processes of interdisciplinary teams moving from research problems to emerging technological outcomes, in order to investigate enactments of interdisciplinarity – that is, technologically-mediated interdisciplinarity 'in-the-making'. The central research question asks:

> *How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?*

1.2.1 Introducing University X

This study is an ethnographic, collective case 'praxiography' of the 'laboratory life' of three technologically-mediated 'interdisciplinary' research projects, based at a University in the USA, 'University X'. Praxiography employs the methods of ethnography to address the materiality of practice, focussing 'the ethnographer's lens… at the level of practice' (vu Henry, 2018: 69 - 70).[5] Whilst the trend towards interdisciplinary research has arisen across the USA, Europe and Asia-Pacific, among other places (Ledford, 2015; Gleed and Marchant, 2016), the USA has put in place significant strategies, policies and structures designed to foster interdisciplinarity (Sá, 2007). This burgeoning interdisciplinary

[5] See Chapter 3 (Methodology) for full discussion.

ecosystem, alongside high levels of investment into new technological development, motivated the choice to conduct fieldwork at a University in the USA.

Through preliminary 'scoping' visits across three US Universities, I crucially secured access to an interdisciplinary research catalyst ('Hub') based at University X, within which I found my 'home-base' during data collection as an official Visiting Researcher. The institutional ethos of University X, with a particularly strong socio-historical culture of interdisciplinarity and technological innovation, combined with the suitability for empirical investigation of some of the research projects which it housed, motivated my selection of this site for the study. The narrative of the findings chapters of this thesis follows three interdisciplinary research projects at University X: a Medical Robotics project (CS1), developing a robotic device for administering liver surgery; a Digital Humanities initiative (Cs2), building new software for historians; and an Energy project (Cs3), working to develop a new Energy grid.[6]

1.2.2 Introducing the cases

The three research projects, the case studies, were purposefully selected. As will be fully discussed in Chapter 3 (Methodology), projects were initially chosen according to certain criteria, including the intention to develop technologies during their research, and their 'official' status as 'interdisciplinary' endeavours approved and funded by significant granting agencies, and supported to some extent by University infrastructures. A collective case study was selected in order to access a broad 'spectrum' of disciplines across the University, to investigate how interdisciplinarity might be enacted differently, or similarly, when different disciplinary fields and actors are involved. Indeed, the cases chosen represent a wide array of diverse disciplines and different iterations of interdisciplinary researchers and objects working together. Technology mediates all the

[6] Anonymised; see chapter 3 (Methodology) for more detail.

projects in different ways and to differing extents, but technological development is inextricably linked with the research aims across all three projects.

The first case study (CS1) focusses on the Medical Robotics project, building a robotics platform which integrates a steerable needle in order to improve access and accuracy in radio-frequency ablation (RFA) procedures targeting tumours in the human liver. The 'core team' consists of a small number of engineers and clinicians, working on the design and development of the needle, and its integration into a prototype robotic, surgical device. The exploratory conversations I held with the PI, alongside my initial scoping desk research, produced thought-provoking early ideas around the conceptualisation of interdisciplinarity in a project involving engineers and medical doctors, indicating that this would be an interesting case to investigate.

The second case study (CS2) follows the Digital Humanities project, designing a prototype digital visualisation tool for humanities data. This software, which connects linked data sources to graphing tools, aims to provide a framework for historians and other humanities researchers to access and explore historical data. Researchers on the 'core team' represent 'disciplinary inputs' including history and software engineering. The project is situated within a research centre at University X, based at the School of Humanities and Sciences, exploring digital tools and methods to 'create new knowledge' in interdisciplinary humanistic inquiry. Early conversations with the team suggested that this would be an interesting environment within which to investigate interdisciplinarity, due to a conscious dialogue around, and considered promotion of, the phenomenon. This case was also selected out of an interest to explore what may be termed a nascent interdisciplinary field, the 'Digital Humanities' (Berry, 2011).

The third case (CS3), the Energy project, or 'Energynet', aims to work towards the construction of an improved power grid to minimise the consumption of energy. The ultimate goal of this well-funded initiative is to develop integrated hardware and software to aggregate and control energy resources, creating a more sustainable and reliable grid to

manage renewable energy. The project is predominantly funded by a United States government agency which funds research into advanced energy technologies, and it partners with several external stakeholders, including high-profile technology companies. This case was selected in part not only because of its 'narrower' disciplinary 'mix', but also due to its direct industry and government collaboration at inception, which seemed to be an interesting project dimension with respect to consideration of its interdisciplinarity.

Drawing from Callon's (1986) four 'moments' of translation (problematisation, interessement, enrolment and mobilisation, as defined in Chapter 2), each case narrative will follow a different 'token' - that is, a human or non-human focal actor whose path can be followed to find a 'way through' a complex actor-network - through the unfolding processes of the interdisciplinary teams moving from research questions to emerging technological outcomes. In order to do so, the study moves between observations; in-depth, semi-structured interviews with 'interdisciplinary' researchers; documentary gathering, review and analysis; and technical artefact identification and photography, across the three cases, to explore in detail enactments of technologically-mediated interdisciplinarity.

1.3 Structure of the thesis and chapter outline

This thesis consists of eight chapters and can be broadly divided in three parts.[7] The first part (Chapters 1, 2 and 3) presents motivation for this work, with a critical review of the literature that provides a contextual, conceptual and methodological framework for the study. The second part (Chapters 4, 5 and 6) presents the study findings, each chapter focussing on a different case, with some initial discussion that draws on wider literature. The third part (Chapters 7 and 8) draws on relevant literature to provide in-depth discussion and synthesis of the findings. The focus of each chapter is briefly introduced and outlined below.

[7] See Appendix A for overview of thesis terminology.

Part 1: Study rationale and design

The current chapter serves as the introduction to the study. Chapter 2 presents a review of the relevant literature, contextualising the study within an existing conceptual, theoretical and empirical framework and motivating the research question, laid out at the end of the chapter: 'How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?'. This chapter will draw together and critique relevant literature on interdisciplinarity, disciplinarity and technology, particularly within research in Higher Education, with key ideas and studies from Actor-Network Theory (ANT).[8] I will argue the need to move away from technological as well as social determinism, considering interdisciplinarity and technology as social as well as material practice. This entails shifting away from 'standard narratives' around (inter)disciplinary perspectives towards inter(disciplinary) realities in order to acknowledge the complexities of technologically-mediated interdisciplinarity 'in practice'. The chapter also highlights some key studies upon which this research builds, such as Mol's (2002) *The Body Multiple*, Barry, Born and Weszkalnys' (2008) eighteen-month study of interdisciplinarity, and Rimpiläinen's (2012) tracing of an emerging educational technology through an interdisciplinary research project.

Chapter 3 explains the rationale for the study's research design and methodological framework, justifying my choices around the methodological approach in accordance with the research question. Actor-Network Theory (ANT) offers a valuable framing for interrogating the 'unity of interdisciplinarity' (Barry and Born, 2013: 5), and this chapter elaborates upon concepts introduced in the literature review, such as 'generalised symmetry' and 'translation'. I have argued that novel methodological (and theoretical) development is necessary to generate new insights into how interdisciplinarity 'happens' in Higher Education. Having presented the theoretical foundations through which to do

[8] There are a very small number of ANT-inspired studies which examine 'interdisciplinary' fields akin to the three case study 'areas' chosen, and these will be attended to throughout the thesis.

so in this chapter, I now present the methods adopted in this thesis, keeping in mind that ANT is 'notoriously vague in terms of methods' (Rimpiläinen, 2010: 1). Engaging with ANT in order to attune to emergent technologically-mediated interdisciplinarity as the object of my empirical study, and drawing on the approach as a conceptual, theoretical and methodological practice, I explain how it helped to define my research question, as well as how to address it in practice. I describe my rationale in choosing a 'praxiographical' ethnographic collective case study through which to accomplish the investigation, and present a detailed description of the empirical setting, including the specific choices made when navigating access to the field; potential limitations, including my own disciplinary positionality; the qualitative methods of data collection and analyses I adopted; and the narrative approaches and ethical considerations which I engaged in order to attend to the depth, heterogeneity and complexity of technologically-mediated interdisciplinarity 'in-the-making'.

Part 2: Study findings

Chapter 4 is the first of three empirical findings chapters, and examines enactments of interdisciplinary practices within a Medical Robotics project (CS1). The narrative of this chapter follows the project, introduced above, working to develop a robotic device for administering liver surgery (for clinical adoption). The token followed here is a steerable needle, which initially acts as a device of interessement (that is, an actor which 'interests' other actors in the problem or project at hand), and this assists in laying out the findings of the study whilst simultaneously conducting analysis. Following the path of the needle through four moments of translation, I explore how the shared research aims are tackled in practice when different 'disciplinary' approaches, most notably engineering and medicine, are brought to bear upon them. Situated interdisciplinarities are enacted during different moments within this case, even as the researchers' ideas around 'dichotomous worlds' and project 'ownership' persist. The steerable needle is critical in accomplishing this interdisciplinarity. During the moments of enrolment and mobilisation, experiments

in the project's 'Zeevo' lab participate as a site of interdisciplinary negotiations, where multiple ontologies coordinate in different ways and (partial) translation is brought about. This chapter represents the first 'application' of Actor-Network Theory (ANT) in my thesis. As such, it includes some methodological description, indicating how I have used ANT in practice to explore technologically-mediated interdisciplinarity. It is important to include this since ANT 'breathes' through its use, and so the methodological and theoretical chapters must be supplemented in this way.

Chapter 5 presents an empirical account of findings from the Digital Humanities project (CS2). The narrative follows the malleable concept of 'encoding a humanities epistemology' into new software, 'Data Biro', in order to evoke the socio-materiality of interdisciplinarity. The concept, an interdisciplinary object, is used by one of the team, Nicola, as a tool to promote and foster (dialogue around) interdisciplinarity, bringing different disciplinary researchers together through an active problematisation of disciplinary knowledge practices. This is an explicit attempt to mobilise an interdisciplinarity and 'embody' inter/disciplinary practices in Data Biro. In this way the materiality of interdisciplinarity moves through the concept and its related diagrams, and I trace how the concept 'gathers' enrolments of actors as allies into the network. There are emerging multiplicities, and tensions between, multiple concept(s), and as such, a 'theoretical' translation of the concept token happens, to a certain extent, but there is resistance to an 'equivalent' enactment of the concept technologically. Some engineers 'buy into' the aspirations behind the concept during a design workshop, using it theoretically in their own practices (and thus mediating the project's interdisciplinarity), but there is a resistance to its 'practical' mobilisation. Ultimately, a 'version' of Nicola's interdisciplinarity is privileged, displacing other ontologies (and their 'versions' of 'success' for the project).

Chapter 6 is the last of the three empirical findings chapters, exploring enactments of interdisciplinarity in an Energy project (CS3) by following a postgraduate researcher,

Marco, as a human token. Marco's interdisciplinary agency is constructed through his relations with other actors in the 'Energynet' project, as it moves through technological research and development practices. The project grant proposal was formulated through (interdisciplinary) connections with industry and government. Shared 'visions' of an 'ideal' energy future, potentially achieved through 'real-world' applications of the technologies-in-development, draw a variety of actors towards the project. There is an emphasis on engineering disciplines, as sociology and others 'disciplinary inputs' resist enrolment, while a new project laboratory at University X becomes a site of interdisciplinary negotiations. As technologies 'come together' in the lab, so do the human and non-human actors entangled with them. This particular project network does not reach the final moment of translation, mobilisation, as the technologies developed struggle to move from the university environment into industry, despite the potential for representation through Marco's, and the new project laboratory's, emerging (interdisciplinary) agencies.

Part 3: Discussion and conclusions

Chapter 7 is a cross-case discussion of the findings from the previous three chapters, according to the study's research question, in relation to existing literature across the STS and Education fields. This chapter discusses what has been uncovered about the socio-material practices of interdisciplinarity in research projects co-developing new technologies in a US University. Interdisciplinarity was practiced in multiple ways by different project actors, across the three projects (according to the multiplicity of objects and different disciplines). Emerging and interconnected inter(disciplinary) realities have been enacted through project practices, across a multiplicity of (inter)disciplines, and following tokens has helped to bring situated interdisciplinarity into the foreground. Moving away from 'traditional' framings of interdisciplinarity, through the theoretical and methodological underpinnings of this study, distributed interdisciplinarities are found to be mediated and embodied by technologies-in-development, often irreducible to their

antecedent parts, and made of relational tensions. This chapter also explores *how* such a complex and 'slippery' phenomenon was handled empirically, and how this productively further 'opened up' technologically-mediated interdisciplinarity.

The final chapter, chapter 8, concludes the study with a discussion of the thesis' contributions. This research generates new insights and advanced understandings into how interdisciplinary research happens 'in practice' in projects developing new technologies in Higher Education. This chapter also considers some limitations, re-visits my own researcher positionality, reflects upon future practice (including metacognition for interdisciplinary researchers), and finally suggests productive directions for future research. The study findings bring forward, and contribute to, advanced conceptual thinking around the multiplicities of interdisciplinarity, moving away from technologically and socially deterministic framings of technologically-mediated interdisciplinarity in Higher Education. This includes reflection on how the multiplicity of realities participate in interdisciplinarity, particularly when there are 'pressures in the research team to produce a singular account from this multiplicity rather than represent the multiple ontologies of research practices' (Fenwick and Edwards, 2010: 158).[9] This chapter reflects upon how the findings chapters discussed the shift in emphasis from a focus on different perspectives on knowledge, to ways of actually thinking about and experiencing the world. This move from (inter)disciplinary perspectives to (inter)disciplinary realities, drawing from ANT to productively 'open up' multiplicities, illuminates how non-humans also participate in socio-material research practices in Higher Education. This work builds upon, and contributes to, the existing body of knowledge around interdisciplinarity, to understanding the development of new technologies, and to the application of ANT in

[9] Across the cases, this is often about which 'realities-in-the-making' are privileged (Oliver, 2012; Woolgar and Lezaun, 2013). "We should not expect the ontologies produced by different practices to 'collapse' to a single, foundational 'truth'; indeed, in some cases, resolution of any kind may be impossible" (Oliver, 2012: 443).

Education, with broad implications for the substantive promotion of a more nuanced view of technologically-mediated interdisciplinary practices.

Beginning to (un)settle technological and interdisciplinary practices

This thesis will thus examine how emergent interdisciplinary research practices are enacted in technology projects in Higher Education, contributing to enhanced theoretical, methodological and empirical understandings of socio-material interdisciplinary practices of scholarly research and technology development. The focus is on overcoming the serious paucity of valuable research into the co-construction of interdisciplinary knowledge and technology within collaborative projects. Having introduced and given an overview of this thesis, the next chapter engages with the relevant literature to begin (un)settle matters of technologically-mediated interdisciplinarity practice.

CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter will establish the need for an enhanced conceptual framing of technologically-mediated interdisciplinary practices in Higher Education, presenting the theoretical foundations through which to do so. By drawing together and critiquing relevant literature on interdisciplinarity, with key studies from Actor-Network Theory (ANT), new explorations of interdisciplinary research 'in practice' can happen. The literature review discusses findings from studies on interdisciplinarity to contextualise this research within an existing empirical and theoretical framework, and to motivate the study's research question. This study aims to build conceptually upon existing scholarship in order to generate deeper insights into interdisciplinary research projects developing new technologies.

Section 2.1 will unpack tensions in current scholarship around technologically-mediated interdisciplinary research in Higher Education. There are as yet only indications of how disciplines and technologies-in-development shape each other, and many studies tend towards technological determinism. Next, reflecting upon current enthusiasms around interdisciplinarity, particularly within the USA, and as such arguing why it is important to study the phenomenon, I explore and critique conceptualisations of both interdisciplinarity and disciplinarity. In particular, there is a proliferation of socially deterministic work, reducing interdisciplinarity to integration and boundary-crossing. The review will also highlight some promising research studies in the area which begin to consider interdisciplinarity as material practice.[10] Acknowledging the call by Barry and Born (2013: 42) to 'raise the prospect of a re-evaluation of interdisciplinarity', the review finds that more nuanced and critical framings of interdisciplinary research in technology projects – moving away from both technological *and* social determinism - particularly

[10] I follow vu Henry (2018: 39) in her '*relational* and *performative* definition of practice'.

within Higher Education in the USA, are needed to take into account the complexities inherent in how interdisciplinarity happens 'in practice'.

Section 2.2 will introduce Actor-Network Theory (ANT) as a valuable framing for attuning to and interrogating interdisciplinarity in research projects developing new technologies as the object of study. Research is moving towards an enhanced theoretical understanding of technologically-mediated interdisciplinarity, but the positioning of technology and conceptualisation of interdisciplinarity is nevertheless a weakness. This section reinforces the need for research which uses enhanced conceptual framings of technologically-mediated interdisciplinarity. I will outline some central tenets of, as well as criticisms and responses to, ANT, and how it has been 'applied' in the field of Education. The section will then narrow its focus looking at how interdisciplinarity, or interdisciplinary knowledge work, can be conceptualised through the lens of ANT. Finally, I will show how drawing on the framing as a conceptual, theoretical *and* methodological practice can account for the complexity of relations that participate in interdisciplinary research by acknowledging the heterogeneities of interdisciplinary researchers, concepts and technologies. Such novel theoretical (and methodological) development, moving away from 'conventional' (inter)disciplinary perspectives towards (inter)disciplinary realities, is necessary to generate new insights into interdisciplinarity in practice in Higher Education. Having framed my research area, I will then delineate the research question for this study, as motivated by the literature.

2.1 UNPACKING TECHNOLOGY AND INTERDISCIPLINARITY

2.1.1 Technological mediation in research and scholarship

There is a growing body of literature which looks at the relationships between technological advances and reconfigurations of scholarly research across disciplines, that is, how advances in technologies are fundamentally reconfiguring the way scholarly research is conducted across all disciplines (Fry and Talja, 2007; Dutton and Jeffreys, 2010; Meyer and Schroeder, 2015). 'Across the university the way in which we pursue

research is changing, and… technology is playing a significant part in that change… It is becoming more and more evident that research is increasingly being mediated through… technology', points out Berry (2012: 1). Indeed, innovative technologies have been positioned as 'powerful mediating artefacts' in interdisciplinary endeavours (Scanlon et al., 2013: 49); for example, Scanlon and Conole (2018) investigate interdisciplinarity in technology-enhanced learning (TEL). Wessels and Craglia (2007: 705) explore the relationship between academic knowledge and research practices, finding innovation within technologies to be important, and Wuchty, Jones and Uzzi (2007) suggest that the process of knowledge production has fundamentally changed with the mediation of innovative technology.

Within this body of literature, there are studies which look at how technologies mediate research and scholarship within individual disciplinary silos in Higher Education, since 'adoption and application of technologies across scholarly communities [is] not uniform' (Palmer and Cragin, 2008: 165), and 'some fields and disciplines seem to have more potential to benefit from [technology] than others' (Houghton, Steele and Henry, 2004: 233). Indeed, 'mono-disciplinary' collaborative practice using technology has been investigated in great detail. For instance, Bezemer et al. (2013) examine the role of the scalpel as a mediating technology in surgery, and Collins, Bulger and Meyer (2011) look at technology mediation in the humanities. Despite the suggestion that 'technology offers an obvious way to break down the disciplinary boundaries in traditional academic practice' (Scanlon et al., 2013: 631), there does not, however, seem to be an interdisciplinary equivalent with this level of analysis and rigour, and therefore the ways in which technology mediates the co-construction of new knowledge in interdisciplinary research projects is currently neglected.

Furthermore, the majority of the research in the area of scholarship mediated by technology, particularly that of a collaborative nature, has focussed upon communication and orchestration aspects, that is, underlying Information and Communications

Technologies (ICTs) used for organisational purposes (Borgman, 2007). For example, in her study of ICT appropriation in the field of corpus-based linguistics, Fry (2004) aims to extend Whitley's (1984) theory of the intellectual and social organisation of academic fields to explain variations in digital resources across fields, applying the concepts of 'task uncertainty' and 'mutual dependence' to explore scholarly communication practices in the digital realm. Research in the area of the development of technology *during* scholarly research is under-developed, however, and related literature with regards to interdisciplinary scholarship is even less so. As the literature review will discuss, interdisciplinary research is concerned with the generation of new knowledge. Technologies-in-development arguably have a closer relationship with knowledge in how they are developed and appropriated (Shinn, 2005), and therefore a focus on them, rather than ICTs (for organisational and communication purposes), constitutes a more suitable, and timely, route of investigation.

2.1.2 Technologically-mediated interdisciplinary research in Higher Education: tensions in current scholarship

My literature review has found many studies in the area of technology mediation within interdisciplinary practice which take the position, deliberately or otherwise, of technological determinism – or, at least, that are 'well-meaning but naïve in relation to… technology' (Oliver, 2016: 52). With the under-theorisation of technology,[11] they assume that technology only facilitates interdisciplinarity, or provides 'a solution to the problem of collaboration' (Haythornthwaite et al., 2006: 144), for instance, in the case of Hermann, Rummel and Spada's (1998) comparative study of net-based interdisciplinary collaboration. Berry (2011: 13) argues that new computational approaches *allow* for disciplinary hybridity within Higher Education, and the National Academies (2005: 35) similarly view technologies as drivers of interdisciplinary research. In doing so, these

[11] Outside of the Philosophy of Technology (e.g. Feenberg, 1999).

studies 'fail to acknowledge the negotiation of practices and co-evolution of practices and technology that are involved' (Haythornthwaite et al., 2006: 144).

Much of the research that has been carried out into the role of technology in supporting interdisciplinary practice relies on the technologically-deterministic concept of 'affordances' (that is, the way in which technology supports certain actions) (Oliver, 2005). This work investigates how the 'affordances of different technologies influence…mediation' (Clough, Conole and Scanlon, 2010: 6), often arguing that the 'affordances of new technologies offer something of a step change, providing a wide variety of different ways in which academics can now communicate, collaborate, critique and share knowledge' (Conole at al., 2010: 14). But the 'effects' of or 'uses for' technology in scholarship, and therefore on interdisciplinary practice, are not the entire story (e.g. Friesen, 2009). Oliver (2016: 40) points out that Latour (2005), for example, has challenged the 'conception of modern technology as essentially instrumental', and de Vries (2013: 26) differentiates between 'technology as artifacts', as well as knowledge, activities or values, for example. The positioning of technology and conceptualisation of its mediation in most existing literature is a weakness in the bulk of current research into interdisciplinary practices, and it is this approach which can lead to outputs of limited value.

Other studies address these deterministic concerns, moving away from ideas of technological affordances, by beginning to touch upon ideas of co-production,[12] exploring some complexities of interdisciplinarity by taking a socially shaped approach (MacKenzie and Wajcman, 1985; Wessels and Craglia, 2007). The social shaping perspective (Williams and Edge, 1996), drawn from the broader field of Science and Technology Studies (STS) states that 'technologies do not just spring into being, but are invented, designed, implemented, and used by people in particular social contexts' (Graham and Dutton,

[12] Jasanoff (2004: 2-3) suggests that 'co-production is shorthand for the proposition that the ways in which we know and represent the world… are inseparable from the ways in which we choose to live in it… Co-production can therefore be seen as a critique of the realist ideology…'.

2014: 13). For example, Trevino, Lengel and Daft (1987) argue that an individual's reported perception of technology within interdisciplinary work shapes the technology; Collins, Bulger and Meyer (2011: 76) found that researchers' uses of, and attitudes towards, technologies are affected by existing disciplinary habits and preconceptions; Fry and Schroeder (2010: 263) explored how tools are shaped by different disciplines; Pinch and Bijker (1984) suggest how the process of designing technologies reflects 'social interests', shaped by different and competing groups over time; and Fry and Talja (2007: 130) argue that '…the shaping of digital resources is not simply a matter of technological innovation… A focus on disciplinary cultures [can help] us to reach a closer understanding'.

Indeed, 'if technology is understood in this relational way – as something in flux, its meaning determined in important ways by the contexts and manner of its use – then this requires us to approach its study in different ways' (Oliver, 2012: 442). Selwyn (2010: 65) explains that technology should be viewed as 'socially constructed and negotiated rather than imbued with pre-determined characteristics, developing objective and realistic accounts of technology use in situ', adding that 'more research is required that moves away from a means-end thinking about how best to harness the presumed inherent educational potential of… technology, and instead focuses on the socially contested and socially shaped nature of technology'. Studies must '…reconsider our research practices… in doing educational research by drawing attention to a different way of conceptualising the technologies we apply, evaluate and study', adds Enriquez (2009: 386). This is particularly crucial in research environments where the 'creation of new technologies relating to [the team's] research endeavour' is not uncommon (Haythornthwaite et al., 2006: 157). However, there are as yet only indications of how disciplines and technologies mutually shape each other (Fry and Schroeder, 2010: 268), and, as stated, the majority of research in the area of interdisciplinary scholarship has focussed solely upon the communication and orchestration aspects of technologies (Borgman, 2007). If a range of technologies participate in, shape and are shaped by interdisciplinary research, then they

should participate in new explorations of interdisciplinarity.[13] 'Recognising technologies-in-use as agential in co-shaping… our lifeworld suggests educational researchers may be obliged to consider such technologies as relevant research participants', argue Adams and Thompson (2011: 733). Whilst the use of the social shaping approach presents an advancement in the conceptual development of research into technologically-mediated interdisciplinary practices, more nuanced theoretical, empirical and methodological exploration is nevertheless required. In order to begin to do so, what is meant by 'interdisciplinarity' must be unpacked, particularly in relation to technology and Higher Education.

2.1.3 Trouble with the 'undeniable momentum' of interdisciplinarity

The concept of interdisciplinarity is not new – despite Klein's (1990) attribution of its 'historical novelty' - but the 'buzz' around it is (Leitch, 2000; Barry and Born, 2013; Jacobs, 2013). Increasing prominence has been given to interdisciplinary collaboration as a means of addressing the most pressing challenges of the 21st century within academia, industry and government, and this shall be discussed below (Graff, 2015; Frodeman, Klein and Pacheco, 2017). It is broadly understood as involving the combination of two or more academic disciplines, and is therefore often conceptualised as disciplinary 'integration' (MacLeod and Nagatsu, 2018). However, as pointed out by Klein's (1990, 2010) work, it is an imprecise concept, with no clear universal definition (or approach). Not only has literature on interdisciplinarity been developed by researchers from a wide and divergent number of fields, but the writing covers a huge range of topics, written for different purposes - from theoretical, to methodological, to pragmatic (across the 'why', 'what' and 'how' of interdisciplinarity) - and for diverse audiences. There are numerous accounts and overviews of the topic approached from various perspectives ranging from challenges and barriers against interdisciplinarity (Bauer, 1990), interdisciplinary pedagogy, teaching

[13] For example, technologies-in-the-making might act as 'boundary objects' in interdisciplinary research projects (Bowker and 1999), as suggested by DesPortes, Spells and DiSalvo (2016).

and learning (Apostel et al., 1972; Spelt et al., 2009; Ng et al., 2011; Augsburg, 2016), the history and organisational aspects of interdisciplinarity (Klein, 1990; Weingart and Stehr, 2000), and (systematic) literature reviews of interdisciplinarity 'in general' (Aboelela et al., 2007; Chettiparamb, 2007; Jacobs and Frickel, 2009), to typologies and 'definitions' of interdisciplinarity (Huutoniemi et al., 2010; Klein, 2017) (as further discussed below), interdisciplinary careers in academia (Müller and Kaltenbrunner, 2019), best institutional practices for cultivating interdisciplinarity (Holley, 2009), interdisciplinary teams (rather than interdisciplinary individuals) (Lakhani, Benzies and Hayden, 2012; Nancarrow et al., 2013) and the science of team science (SciTS) as interdisciplinarity (Fiore, 2008), 'frameworks' to facilitate the design of interdisciplinary research (Tobi and Kampen, 2018),[14] assessing and evaluating interdisciplinarity through 'best practices' (Porter et al., 2006; Repko, 2008; Lyall et al., 2011; Lyall, 2019; Inventing Indicators of Interdisciplinarity, 2019), and 'enhancing' interdisciplinary communication and language (Monteiro and Keating, 2009). Approaches differ significantly as a result of philosophies, contexts and audiences (Frodeman, Klein and Mitcham, 2010; Foshay, 2011).

Yet as Miles and Rainbird (2014) point out, the term 'interdisciplinarity' has become a modern-day 'buzzword' in research across numerous fields, often used ambiguously, and therefore merits more substantial exploration. Many policy interventions, theoretical literatures and empirical studies concerned have assumed an unquestioned integrative model of the phenomenon, in which it is brought about through the integration of 'two or more disciplines' (Mansilla and Gardner, 2003: 160). Repko (2008: xiii) comments that 'the majority of definitions of interdisciplinarity focus on integration', and Newell (2001: 1) regards 'synthesis or integration [as]… the distinguishing but elusive characteristic of interdisciplinary studies'. Indeed, there are a number of typologies of interdisciplinarity in which it is conceptualised as synthesis, or as disciplinary 'boundary-crossing'. For

[14] Yet, as previously acknowledged, the area of interdisciplinary *research*, based within the Higher Education sector, is under-researched, with some exceptions (e.g. Cummings and Kiesler, 2005; Barry, Born and Weszkalnys, 2008; Derrick, Falk-Krzesinski and Roberts, 2011).

example, Spelt et al. (2009: 366) argue that interdisciplinarity is associated with 'boundary-crossing skills…for instance, the ability to change perspectives [and] to synthesise knowledge of different disciplines' and Blackwell et al. (2009: 16) write that 'interdisciplinarity involves crossing… essential boundaries within which knowledge is organised'. The US National Academy of Sciences, National Academy of Engineering and the Institute of Medicine report *Facilitating Interdisciplinary Research* (2005: 26) defines 'interdisciplinarity research' as follows:

> 'Interdisciplinary research (IDR) is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialised knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or field of research practice'

Furthermore, according to Klein and Newell (1997: 393), interdisciplinarity is:

> '… a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession'

Most of these conceptualisations of interdisciplinarity and interdisciplinary research in Higher Education reduce the phenomenon to only human interactions and their disciplinary affiliations (Lattuca, 2002). For example, Carr, Loucks and Blöschl (2018) developed a framework for supporting interdisciplinary research based solely on human capital. I argue that this approach should be broadened, and agree with Frickel, Albert and Prainsack (2017: 6) that much 'work on interdisciplinarity misses or overlooks the complexity of interdisciplinarity politics and the social heterogeneity of interdisciplinary practices… Understanding interdisciplinary collaboration thus requires moving beyond a narrowly focused interactionist perspective'. There is a need to attend to the roles which non-humans play in interdisciplinary practices, moving away from socially deterministic, humanist explanations and paradigms of interdisciplinarity which permeate modern

thought. ‘Analysis of the experience of interdisciplinary working to date has paid insufficient attention to the objects through which it is conducted’ (Donaldson, Ward and Bradley, 2010: 1523).

On this background, there has been an ongoing, re-emerging cognisance of interdisciplinarity as a ‘pervasive form of knowledge production’ (Mansilla and Gardner, 2003: 160), in part due to the radical shift in how technology shapes information dissemination in the modern world (Webster, 2006). ‘In recent times, the theme of interdisciplinarity has gained popularity in policy, practice, teaching and research circles’, explains Chettiparamb (2007: 1), and Klein (1990: 38) describes an ‘undeniable momentum’ around the phenomenon in the latter part of the 20th century. Interdisciplinary exchange is often seen as a hallmark of contemporary problem-solving (Tait and Lyall, 2001; Miles and Rainbird, 2014) and, as suggested, benefits of interdisciplinarity are deemed to include bringing ‘multiple perspectives to bear on a problem… addressing the complexity of current phenomena’ (Haythornthwaite, 2006: 1079), and creating ways to address societal problems that cut across traditional mono-disciplinary fields (Hargreaves and Burgess, 2009). Indeed, it is widely viewed as beneficial for connecting science with society and the economy, and for bringing multiple perspectives to bear on complex problems. This optimism has spurred efforts at various levels across different sectors towards interdisciplinary projects and centres (Rhoten and Parker, 2004; Porter and Rafols, 2009). As such, interdisciplinarity is often framed as an inherent good within and beyond the University (Welch, 2011, 2012). For example, Repko, Newell and Szostak (2012: xv) maintain that ‘developing a comprehensive understanding of complex societal problems, and especially resolving them, requires interdisciplinary thinking and research’, and a Guardian article proclaims that ‘The university of the future will be interdisciplinary’ (Irani, 2018). The current preoccupation with interdisciplinarity, this ‘interdisciplinary hype’ (Jacobs, 2009), and the increasingly high stakes with which it is associated, warrant urgent empirical investigations into the phenomenon.

Indeed, modern day research issues are often framed as requiring academics to collaborate on solutions that transcend *disciplinary* perspectives, and as such funding bodies increasingly look for *interdisciplinary* proposals. There are, in particular, growing calls for the use of interdisciplinary research methods to respond to 'real-world' issues. Interdisciplinary research and education are thus a major trend in Universities and research funding agencies, particularly in Europe and North America (LERU, 2016), and Boix Mansilla, Lamont and Sato (2016: 572) argue that interdisciplinary research is viewed by 'scientific agencies and policy makers as the philosopher's stone, capable of turning vulgar metals into gold'.

But this framing of interdisciplinarity, in modern parlance,[15] often as an assumed and unquestioned 'good' - a 'less constrained' option to disciplinary thinking, or as a way to provide 'responsible' and accountable research - can be problematic. For example, interdisciplinarity has become 'a programmatic, value-laden term [standing for] reform, innovation, progress', suggest Weingart and Stehr (2000: xii), and Frodeman, Klein and Mitcham (2010: xxxii) argue that 'interdisciplinarity is simply a means. But to what end? Pragmatically put, towards the ends of greater insight and greater success at problem solving'. But there is a need to move away from these 'grand narratives' of interdisciplinarity (Welch, 2011: 32). As Albert et al. (2019: 1) point out, as they problematise the pro-interdisciplinary assumptions underlying health professions education research (HPER) and examine citation patterns, we need to 'critically examine the ubiquitous discourse promoting interdisciplinarity'. Whilst the majority of literature advocates for interdisciplinarity, it is notable that very little is helpful in understanding what interdisciplinarity actually 'is', and as such I, like Jacobs and Frickel (2009: 44), am

[15] Whilst this thesis does not focus on the 'history' of interdisciplinarity, it is important to note that "…utopian calls for restructuring university teaching and research on interdisciplinary lines have a long history. In the United States they date back to the 1930s, with the 'general education' movement and reforms of undergraduate education at elite institutions such as Columbia, Chicago, and Harvard" (Mills, 2013: 582).

'sceptical of a number of the assumptions advanced by advocates of interdisciplinarity'. More critical work investigating interdisciplinary research needs to be carried out.[16]

2.1.4 Politics of relations between disciplinarity and interdisciplinarity in the University

The concept of interdisciplinarity, of course, relies on the existence of disciplines (Klein, 1996; Turner, 2006).[17] "As the composite nature of the term itself suggests, 'inter-disciplinarity' assumes the existence and relative resilience of disciplines as modes of thought and institutional practices" explains Moran (2002: 17). Broto, Gislason and Ehlers (2009), in an interview-based study of motivations for conducting interdisciplinary sustainability research, also suggested that interdisciplinary research practice relies on disciplinary institutions as points of theoretical and methodological reference.

Few problems are confined by disciplinary boundaries, yet the majority of global Higher Education systems - including the focus here on US Universities - remain siloed by discipline, contributing to 'institutional obstacles' which Klein (1990: 38) argues prevents much 'true' interdisciplinarity from taking place. This is particularly the case for University-based research, since 'in most universities, research is organised along… disciplinary boundaries' (Blackwell et al., 2009: 27). Thus, in order to fully un-pack the study of interdisciplinarity, I must also attend to literature concerning disciplinarity (Broto, Gislason and Ehlers, 2009; Hvidtfeldt, 2018). As Szerszynski and Galarraga (2013: 2822) suggest, interdisciplinary research often remains 'unreflective' about the political ways in which disciplines are organised, but disciplinary identity politics take part in interdisciplinarity, and 'doing interdisciplinary work… involves… negotiating… a politics of disciplinary knowledge' (Monteiro, 2018: 156). This of course varies according to individual institutional political economies, and Strathern and Khlinovskaya Rockhill

[16] Some work around this will be presented later in this chapter.
[17] Krishnan argues for 'embracing interdisciplinarity while keeping and nurturing disciplines as the ultimate reference points' (2009: 51). Similarly, a paper by the LERU (2016) argues that it is essential for universities to cultivate both disciplinarity and interdisciplinarity.

(2013), carrying out ethnographic research at the Cambridge Genetics Knowledge Park (CGKP), found that it is important for the thriving of interdisciplinarity to be implanted into responsive and supportive environments.

Firstly, it is important to acknowledge, as (conceptual) ground-clearing, how a number of (inter-related) prefixes to the term 'disciplinary' have developed in the literature. Alongside 'inter-disciplinarity', the focus of this study, multi-disciplinary, trans-disciplinarity (Piaget, 1972), and pluri-disciplinarity are recognised by Chettiparamb (2007: 19) in her review of interdisciplinarity for the Higher Education Academy. Pickering (2013) adds anti-disciplinarity, and Osborne et al. (2015: 2) list 'inter-, multi-, trans-, de-, anti-, in-, meta- and post-' as available prefixes to 'disciplinarity'. Klein (2017) also constructs a framework of inter-, multi- and trans-disciplinarity, distinguishing between major variants within these including instrumental versus critical interdisciplinarity, for example. Eddy (2005: 4) even terms the 'science that precedes the organisation of new disciplines', that is, the practices that precede the formulation of disciplines, as 'ante-disciplinarity'. There is a significant literature which explores these semantic differences, with broad debate about the concepts and their relationships. For example, Lattuca (2002) provides a typology of 'informed disciplinarity' based on thirty-eight interviews with liberal arts faculty members which spans from 'synthetic interdisciplinarity' to 'transdisciplinarity'. Barry and Born (2013: 8) explain that commonly '…a distinction is made between multidisciplinarity, in which several disciplines cooperate but continue to work with standard disciplinary framings, and interdisciplinarity, in which there is an attempt to synthesise perspectives from several disciplines', adding that, 'less clear distinctions are made between interdisciplinarity and transdisciplinarity, and in practice their meanings are often conflated'. Lury (2018) also points out that within interdisciplinarity's long history are its shifting relations with concepts such as multidisciplinarity and transdisciplinarity.

Indeed, there is a vast (often philosophical) literature on disciplinarity and its relationship with inter-, trans-, and multi- disciplinarity. For example, Nowotny, Scott and Gibbons (2001) termed a 'new' method of knowledge production 'Mode-2', aligning broadly with 'trans-disciplinary', in contrast to 'Mode-1' which is generated within a traditional, peer-reviewed 'disciplinary' framework, and in which there is a clear separation of science and society (Gibbons et al., 1994). It was argued that 'Mode-2' included research which 'transcends disciplinary boundaries' (Nowotny, Scott and Gibbons, 2001: 89), and a growing diversity of sites at which knowledge is produced. In this way, interdisciplinarity would represent 'an innovation in knowledge production' (Frodeman, 2010: xxix). Furthermore, Strathern (2006: 196) argues that "rather as existing 'cultures' get in the way of development, existing disciplines get in the way of interdisciplinarity", and Frickel, Albert and Prainsack (2017: 5) point out that interdisciplinarity is often cast as 'an antidote to the limitations of disciplinarity'. There is a broad assumption across much of the literature that disciplinary siloes constrain the development of interdisciplinary knowledge, and that interdisciplinarity is but a 'counter-image' of the strongly established disciplinary institutional structures (Weingart and Stehr, 2000).

Disciplinarity is typically considered as the 'traditional' foundations around which knowledge – and therefore careers, publishing, intellectual identities, funding patronage, performance indicators, and so on - is organised, particularly in and through the University. For Foucault (1977: 223), 'the disciplines characterise, classify, specialise; they distribute… around a norm'; in the *Structure of Scientific Revolutions*, Kuhn (1962) argues that scientific communities are organised around ideas and practices, coining the term 'paradigm' to express the idea that disciplines are arranged around certain ways of thinking; and Piaget (1972) defines an academic discipline as 'a specific body of teachable knowledge with its own background of education, training, procedures, methods and content areas'. 'As currently understood within the academy, disciplinarity relies on the institutional legitimation offered by research funding, university posts, and career hierarchies', points out Mills (2013: 572). 'The value of a discipline is precisely in its ability

to account for its conditions of existence and thus… how it arrives at its knowledge practices', adds Strathern (2004: 5), and 'power for disciplines comes from control over ideas' (Martin, 1998: 129).[18] Yet what constitutes a discipline is itself the subject of some subtle dispute. For example, Lyotard (1984) understands a discipline as a 'specific practice'; Bridges (2006) recognises a disciplinary field as a coherent 'community of arguers'; 'a discipline is many things: a profession, an intellectual endeavour, and a set of academic practices' comments Mills (2013: 571); and "a discipline internally invents, maintains and invests in its 'intellectual turf'", argues Abbott (2001: 139). Becher (1994) claims that each 'academic tribe' inhabits and defends different 'knowledge territories', distinguishing themselves through self-created cultural practices and specific values. 'Generally, disciplines contain a set of instructions on how to generate knowledge including subject definitions, conceptual approaches, cognitive structures, goals and norms (Klein, 1996)', add Broto, Gislason and Ehlers (2009: 3). And as Aram (2004: 381) points out, "[r]ecognising ambiguities in the concept of 'discipline' foreshadows the challenge of defining interdisciplinarity".

But as Graff (2015: 5) argues, interdisciplinarity can also be understood as 'inseparable from [disciplines], not oppositional to them', and other work advocates for a closer, symbiotic relationship between the disciplines and interdisciplinarity (Szostak, 2017). For example, Jacobs (2013) resists the idea of 'disciplinary silos' as 'negative' in his work *In Defence of Disciplines*. Describing the rise of interdisciplinarity in Higher Education, he argues that disciplinary specialisation is purely a 'reaction' to the need to distinguish intellectual and scholarly domains, rather than a constraining force. The idea that disciplines are 'inert', and interdisciplinarity is a counterbalance to this, does not need to be taken as a given, and as such it could be interesting to explore this. Indeed, 'considering disciplines as static irons out the mess of their evolution', point out Donaldson, Ward and

[18] Where Klein (2001: 52) discusses the 'political economy of status hierarchies' referring to disciplinary participants within interdisciplinary research groups, this could be taken further to look at 'hierarchies' within and between assemblages emerging from *interdisciplinary* research practices; from disciplinary knowers, to (inter)disciplinary objects.

Bradley (2010: 1525). Carp (2001: 74) similarly suggests a 'move away from thinking of the disciplines as unique sources or resources for knowledge and thought. We might instead imagine the disciplines as one sort of knowledge formation, of which there are several kinds…'. 'Disciplinary cultures are best treated not as the rigid, well-ordered, fixed bodies of knowledge which often get enshrouded in the structural institutions of universities and in research evaluation exercises, but as flexible resources', argues Pinch (1990: 302), and Haraway (2000: 133) contends that disciplines should be conceptualised as 'entrenched networks', that is, certain 'orderings' of knowledge that offer just one 'take' on the world. Unlike 'inter-disciplines', disciplines may be enacted and repeatedly re-enacted to the extent that they become black-boxed and assimilated in the power structures of the University. The persistence of disciplines "owes much to inertia, path dependency, institutional and professional embeddedness, and what Suchman (2007) calls 'corporate' disciplinary thinking that has ordered the world in the way it is" (Buller, 2008: 396), and thus disciplines do not need to be conceptualised as fixed and homogenous units, as they often are.

Instead, Barry, Born and Weszkalnys (2008) suggest that disciplines are temporary stabilisations of knowledge practices, and it is important to explore this further when studying interdisciplinarity.

> 'More fluid models of disciplinarity are needed [to] take account of the shifting and changing patterns of association as new disciplinary areas come into being, grow and merge with others. They stress the relationships between areas rather than their distinctness… Such ways of viewing disciplinary affiliation are capable of explaining interdisciplinarity not as a special case' (Brew, 2007: 426)

I thus challenge many of the existing conceptualisations and definitions of interdisciplinarity as integration and synthesis of the disciplines as too 'simplistic', based upon unquestioned models of disciplinarity. I agree with Newell (2001) that such complex phenomena cannot be understood adequately by using 'reductionist' disciplinary

approaches, for example, reducing interdisciplinary frictions to 'communication problems' between the disciplines as distinct units. 'The idea that research should become more interdisciplinary has become commonplace… yet the term tends to obscure as much as illuminate the diverse practices gathered under its rubric', point out Barry and Born (2013: i). Indeed, Mäki and MacLeod (2016: 323) suggest that 'there are many more varieties of interdisciplinarity than suggested by typical popular conceptions' of disciplinary synthesis and Graff (2015) makes it clear that discourse on interdisciplinarity is in dire need of greater conceptual clarity.

2.1.5 Interdisciplinary research in Higher Education in the USA: a changing institutional landscape

'In most universities, research is organised along the same departmental lines as the undergraduate degree courses, and therefore follows the same disciplinary boundaries', explain Blackwell et al. (2009: 27). Within the power structures of the University, taking into account the critical literature around the 'nature' of a discipline, disciplines are typically conceptualised as coherent conceptual and organisational 'place-holders' for knowledge construction and their 'communities' (Kockelmans, 1979; Aldrich, 2014). The majority of global Higher Education systems remain siloed by discipline (Klein, 1990, 2008, 2018),[19] yet interdisciplinary research groups, programmes, projects and centres, as well as undergraduate and graduate programmes - and even qualifications at secondary school level such as the International Baccalaureate - are emerging (Frodeman, Klein and Pacheco, 2017). There is a 'new ordering of disciplines' in Higher Education, argues Koski (2011: 148), and Delanty (2001: 6) suggests that there is 'a new role and identity for the university emerging around the democratisation of knowledge…a proliferation of so many different kinds of knowledge that no particular one can unify all the others. The university cannot re-establish the broken unity of knowledge but it can open up avenues of

[19] Becher and Trowler (2001) in *Academic Tribes and Territories* examine the significance of the disciplines on Higher Education practice.

communication between these different kinds of knowledge'. 'Disciplines constitute the modern social order of knowledge, and the order of knowledge is in this sense a political order as well… [however] the organizational matrix of disciplines is beginning to dissolve', add Weingart and Stehr (2000: xi), and Buckler (2004: 2) goes so far to suggest that the modern University is organised around 'the ruins of outmoded disciplinary structures'.[20] Furthermore, Rhoten (2004) interestingly argues that:

> 'Across the spectrum of higher education, many initiatives deemed interdisciplinary are, in fact, merely reconfigurations of old studies—traditional modes of work patched together under a new label—rather than actual re-conceptualisations and reorganizations of new research… Instead of implementing interdisciplinary approaches from the perspective of a thorough-going reform, many universities are simply adopting the interdisciplinary labels without adapting their disciplinary artefacts' (Rhoten, 2004: 6 - 9)

Over time, interdisciplinary movements and endeavours in the United States (and Europe) have happened in different ways, with different outcomes, perpetuating new fields such as bioengineering and nanotechnology (Graff, 2015). There has been scholarly investigation into interdisciplinarity in the American Higher Education (HE) system in particular. For example, Crow and Dabars (2017: 471) explore 'the accommodation of interdisciplinarity within the American research university,' including its 'disciplinary entrenchment'. According to Abbott (2001: 136) in the *Chaos of Disciplines*, 'a long historical process has given rise to a more or less steady, institutionalised social structure in American academia: a structure of flexibly stable disciplines, surrounded by a perpetual hazy buzz of interdisciplinarity'. Payne (1999) notes that from 1986 to 1996, the growth of interdisciplinary programmes in US academic institutions increased almost 75%, concluding that 'the interdisciplinary movement in American higher education appears to

[20] Indeed, interdisciplinarity 'can form part of a more general critique of academic specialisation as a whole, and of the nature of the university as an institution that cuts itself off from the outside world in small enclaves of expertise', argues Moran (2002: 16).

be a significant and continuing one' (Payne, 1999: 175). The National Academies report *Facilitating Interdisciplinary Research* even goes so far as to recommend the alteration of traditional academic structures in the US University in order to 'stimulate new modes of inquiry and break down the conceptual and institutional barriers to interdisciplinary research that could yield significant benefits to science and society'. Indeed, a number of US Universities have institutionally implemented interdisciplinary research initiatives, such as Arizona State University (ASU), for whom the 'advancement of interdisciplinary knowledge production' was an explicit 'design aspiration' in the re-conceptualisation of the University (Crow and Dabars, 2017). There is thus a necessity to further investigate interdisciplinarity as it comes to be institutionalised alongside disciplinarity (Ledford, 2015),[21] and an approach that focusses on Higher Education in the USA makes a strong case, as will be elaborated on in the Methodology chapter of this thesis.

Whilst the trend towards interdisciplinary research has arisen globally (Gleed and Marchant, 2016), the USA has in place significant strategies, policies and structures around interdisciplinarity (Sá, 2007). This burgeoning ecosystem, alongside high levels of investment into new technological development, make the USA a particularly interesting geographical context within which to study interdisciplinarity. As the Higher Education system in the USA moves towards more institutionalised interdisciplinarity, there are in turn significant implications for evaluations of interdisciplinarity, particularly in funding applications. There is a 'chronic difficulty in evaluating interdisciplinarity' (Barry and Born, 2013: 39), which, I agree, often falls to the 'disciplinary assessment of… interdisciplinary work' (Mansilla and Gardner, 2003: 151). Barry and Born (2013: 39) argue that 'interdisciplinarity has a fragile existence due in part to tensions stemming from the submission of interdisciplinary practices to disciplinary evaluation.' This study focusses on generating new insights into aspects of how interdisciplinary research happens in Higher Education in the USA, and this could tentatively have positive

[21] The Beckman Institute at the University of Illinois offers a prime example.

implications for identifying, and therefore evaluating, further interdisciplinary endeavours in the US, and indeed worldwide, academy.

2.1.6 Emerging work on interdisciplinarity 'in practice'

I have found thus far that much literature, particularly in the space of interdisciplinarity *and* technology, lacks criticality and overlooks interdisciplinarity as a material practice, because very few studies look at interdisciplinarity 'in practice'. As such, more research 'in practice' is needed to address these issues I've identified. Interdisciplinarity 'as it happens' is scarcely interrogated, and 'there is little research on how interdisciplinary projects actually work - and do not work - in practice', comment Callard, Fitzgerald and Woods (2015: 1). They continue, in their study of 'Hubbub', a large interdisciplinary research residency at *Wellcome Collection*, that:

> 'We still know remarkably little of the… detail of what it looks and feels like to labour in an interdisciplinary setting. Nor, more importantly, do we have much sense of the consequences of this unfolding, uncertain [and] hybrid [process]… Collaboration is… an historically and culturally specific mode of practice that needs to be constantly interrogated, expanded and torqued… High-quality modes of tracking and tracing should be central to interdisciplinary endeavours' (Callard, Fitzgerald and Woods, 2015: 6)

More research is needed which *does* interrogate and expand the 'unfolding, uncertain and hybrid' practices of interdisciplinarity, that is, the 'plasma' of interdisciplinarity (Latour, 2012: 93), and ways in which to do this will be explored in section 2.2. As has been established, much literature on interdisciplinarity tends to explore 'practical' matters within broad overviews, for example, drivers, challenges and barriers (Siedlok and Hibbert, 2014; The British Academy, 2016), providing 'orderly justifications and typologies for interdisciplinary research alongside prescriptions for overcoming barriers' (Donaldson, Ward and Bradley, 2010: 1525). But 'conducting successful interdisciplinary research is not just a matter of bringing the right disciplines together and overcoming

barriers to collaboration' (Donaldson, Ward and Bradley, 2010: 1526). Critical reflection on interdisciplinarity and its role in addressing complex problems, particularly within technology projects, is constrained by the predominance of conventional, 'traditional' - often positivist - descriptions of interdisciplinarity which are seldom examined or tested against actual practice. 'While there has been some commentary on how… interdisciplinarity demands new methodologies and practices… less attention has been given to what these… might look like' (Miles and Rainbird, 2014: 2). 'Not many projects reveal insights into collaboration experiences', add Jänicke et al. (2015).

My review has found a small number of empirical studies of interdisciplinarity which can, however, confound these standard narratives, beginning to 'critically examine the ubiquitous discourse promoting interdisciplinarity' (Albert et al., 2019: 1), and thus prove enlightening for framing my research. A notable example is Barry, Born and Weszkalnys' (2008) eighteen-month study of contemporary interdisciplinarity, part of the research programme 'Interdisciplinarity and Society: A Critical Comparative Study', which responds to the 'paucity of empirical studies of how interdisciplinarity unfolds in practice' (Barry and Born, 2013: 2). They undertook ten case studies across three interdisciplinary fields (between the social and natural sciences), striving to begin 'to interrogate the unity of interdisciplinarity' (Barry and Born, 2013: 5). In their findings, Barry, Born and Weszkalnys (2008) suggest three 'modes and logics' of interdisciplinarity (e.g. integrative-synthesis, subordination-service, and agonistic-antagonistic modes of interdisciplinarity) that, while not exhaustive, open up the potential to move away from existing conceptions of interdisciplinarity, which try to 'pin it down', towards considering a multiplicity of interdisciplinarity. This study is conceptually and methodologically very interesting and valuable for my research, and whilst I do not borrow directly from these modes and logics, this thesis follows Barry, Born and Weszkalnys (2008: 42) in their call to 'raise the prospect of a re-evaluation of interdisciplinarity'.

In their review of the design and conduct of the *Understanding Environmental Knowledge Controversies* research project, Donaldson, Ward and Bradley (2010) build upon some of Barry, Born and Weszkalnys' (2008) tentative findings, as they too aimed to 'move discussion of interdisciplinarity beyond the well-worn ruts it has created in recent years' (Donaldson, Ward and Bradley, 2010: 1521). My study will build upon a central contribution from their research: their appeal for a move away from 'conventional' conceptualisations of interdisciplinarity, towards considering other actors, that is, non-humans, in definitions of interdisciplinarity. 'A focus on interdisciplinary researchers can cause us to miss the things they work with… The objects around and through which interdisciplinary research is conducted are sidelined by the conventional view that focuses on languages, motivations, and the primacy of disciplinary discourse' (Donaldson, Ward and Bradley, 2010: 1533 – 1534). They suggest that thinking of interdisciplinarity as being 'among disciplines' rather than 'between them' is more productive (Donaldson, Ward and Bradley, 2010: 1527), since this directs attention towards the objects of research, such as technologies, rather than the interface, or space, 'between disciplines'. This insight is very valuable in considering an alternative conception of interdisciplinary research in Higher Education, and in considering the importance of (interdisciplinary) research objects and technologies in these contexts.

Similarly, Mulcahy (2013) challenges strictly human-centred categories of knowing through an investigation of 'interdisciplinary knowledge work' at a University. Drawing in part from Actor-Network Theory (ANT), which this review will return to soon in section 2.2.2, Mulcahy (2013) distinguishes three 'modes' of interdisciplinarity across to her investigation of the STS literature around the phenomenon: traditional (complementarity), contemporary (instrumentality), and emergent (intra-activity). Investigating the 'silent' and embodied instances of 'doing interdisciplinarity', she empirically examines the phenomenon through a mixed-methods approach in the *Interdisciplinary Collaboration Exploration Project*. She concludes that:

> ‘Interdisciplinarity is an effect performed through material objects (e.g. texts, technologies, artifacts, architectures, bodies) and materialising processes (eg. embodied encounters, virtual collaboration)… Knowledge does not reside in individuals; it circulates in relationships, which in turn can coalesce – form seemingly fixed points and foundations (eg. bodies of interdisciplinary knowledge)’ (Mulcahy, 2013: 7)

Mulcahy (2013) and Donaldson, Ward and Bradley’s (2010) suggestions that interdisciplinarity is about material practice prove particularly enlightening for framing my study’s move away from ‘traditional’, socially and technologically-deterministic conceptualisations of interdisciplinarity and technology in research, towards critically looking at the phenomena in practice. Further theoretical and conceptual building on these promising studies is needed to ‘interrogate, expand and torque’ technologically-mediated interdisciplinary research practices.

2.2 THEORETICAL FOUNDATIONS

It has been established that current work in the area of interdisciplinary practice must be conceptually and empirically developed further in order to advance understandings of the socio-material practices of technologically-mediated interdisciplinary research in Higher Education. ‘Rather than assuming that either technology or society are the determining power, sociomaterial analyses propose that technology’s effects arise from the ways in which they are incorporated into networks, rather than being inherent’, explains Oliver (2016: 51). There is a need for enhanced understandings of interdisciplinary practices, which can account for the heterogeneity of participants and relations that participate, in order to acknowledge the depth and complexities inherent in studying interdisciplinary researchers, concepts and technologies, where technology can be understood in relational ways. Drawing on the framing as a conceptual, theoretical and methodological practice, I thus engage with Actor-Network Theory (ANT), particularly the principles of translation and heterogeneous networks, in order to attune to emergent interdisciplinarity as the

object of my empirical study, since it can engage with 'the heterogeneous intricacy of the world, of lived practices, material orders and networks of relations in all their kaleidoscopic complexity' (Nimmo, 2016: xxiii). The section will look at how ANT has been 'applied' in the field of Education, attending to the materiality of non-humans, and how interdisciplinary knowledge work in Higher Education can be conceptualised through this lens. Finally, I will explain how this conceptual development, allowing a move away from 'conventional' (inter)disciplinary perspectives towards (inter)disciplinary ontologies, can generate new insights into how interdisciplinarity 'happens' in practice in Higher Education.

2.2.1 Advancing theory

In line with the conventional 'interdisciplinarity as integration' trope, as outlined earlier, it has been suggested by Haythornthwaite et al. (2006) that technology can be constructed through the 'integration' of disciplinary perspectives, and that differences in disciplinary practices can be 'bridged'. Despite this 'reductionist' framing, this article sits within a nascent field of work which shows deeper theoretical exploration by looking at how innovative technologies can develop *through* interdisciplinary practice. Scholarly discussion of phenomena within this area can thus be built upon further. For example, Galison's (1997) notion of the trading zone metaphor [sometimes depicted as 'borderlands' (e.g. Huber and Morreale, 2002)] to describe interactions among the engineers and scientists who developed radar can inform my research. 'Two groups can agree on rules of exchange even if they ascribe utterly different significance to the [technologies] being exchanged; they may even disagree on the meaning of the exchange process itself', Galison (1997: 783) explains. This echoes Castells' (2013: 38) discussion of the Network Society in which 'conscious social actors of multiple origins bring to the other their beliefs… and even more: sharing a diverse world, thus ending the ancestral fear of the other'. It is not about shared values, but rather the shared value of technology. Research is therefore moving towards an enhanced theoretical understanding of

technologically-mediated interdisciplinarity, but the positioning of technology (and other objects) and its conceptualisation is nevertheless still a weakness. This study aims to address these tensions in order to better acknowledge the complexities involved in understanding how technologically-mediated interdisciplinary collaboration happens.

2.2.2 Actor-Network Theory (ANT)

I have established that the complexities inherent in studying interdisciplinary research, concepts and technologies necessitate a more critical and theoretically-enhanced approach. Actor-Network Theory (ANT) 'sensibilities' serve a conceptual, theoretical *and* methodological role in this study, drawing from key literature in the field including Mol (2002, 2010), Latour (2005), Law (2004), and Fenwick and Edwards (2018). I will introduce and briefly explore ANT, before explaining how I can work with it to advance understandings of the socio-material practices of technologically-mediated interdisciplinary research.

Background, Context and Development

Actor-Network Theory (ANT) is a constructivist, empirically post-structuralist approach to tracing relations and practices within a network in which human and material, or non-human, actors are brought together in the same analytical view (Latour, 1987; Law, 2004; Mol, 2002, 2010; Thompson and Rimpiläinen, 2012; Fenwick and Edwards, 2010, 2018). 'Neither discursive practices nor material phenomena are ontologically or epistemologically prior… Neither has privileged status in determining the other', explains Barad (2007: 152). The conventional binaries between discourse and the material are as such re-considered in the framing. 'ANT does not differentiate between science (knowledge) and technology (artefact)' (Crawford, 2004: 1). 'ANT provides conceptual tools to trace how stable… networks of humans and materials are formed, and how such networks can fail when associations between actors shift or dissolve. These heterogeneous linkages are understood as sociomaterial practices, and the task of the STS researcher is to

analyse the processes that associate different people and objects together into more or less robust network configurations' explains vu Henry (2018: 32).[22]

ANT, or the 'material-semiotic method' (Law, 2009), builds upon work from Shapin and Schaffer (1985), studying the origins of experimental sciences, Bijker, Hughes and Pinch (1987) and Knorr-Cetina (1999), ethnographically studying 'epistemic cultures', among others. It emerged from traditions within the field of Science and Technology Studies (STS), and in particular, the sub-field of the sociology of scientific knowledge (SSK) (Law and Mol, 2002; Jasanoff, 2004; Suchman, 1985, 2006; Hackett et al., 2008; Sismondo, 2010; Vertesi and Ribes, 2019).[23] ANT shares foundations with the Social Construction of Technology (SCOT), a sub-set of the social shaping stance (Bijker, 1995; Bijker and Pinch, 2012), emphasising the social and political processes around technological development. SCOT draws attention to which different social groups have interests in shaping the design (and use) of technologies-in-development, and thus give meaning to technology through 'flexibility in how people think of, or interpret, artefacts… [and] flexibility in how artefacts are designed' (Pinch and Bijker, 1984: 421).

ANT is most commonly traced more specifically to the work of STS scholars Callon and Latour in the early 1980s (Latour, 1987, 2005; Callon, 1986, 2012; Latour and Woolgar, 1979). Their initial approach is termed Classic-ANT in later scholarship, and aimed to disperse binary, dualist categories, such as the social and the natural. A key foundational text within ANT is Latour and Woolgar's (1979) *Laboratory Life*, a 'laboratory ethnography' of 'doing science' at the Salk Institute in San Diego in which they asked 'How are the facts constructed in a laboratory, and how can a sociologist account for this construction?' (Latour and Woolgar, 1986: 40). This case study highlighted how the production of knowledge did not just involve human beings but was also dependent on a

[22] ANT is concerned with 'precarious relations… a concern with materials of different kinds, with how it is that everything hangs together' (Law, 2009: 145).
[23] There is a rapidly growing literature which borrows from Actor-Network Theory (ANT), although it remains a relatively niche sub-section of the broader field of Science and Technology Studies (STS).

range of non-humans. Indeed, a historical tradition of ANT is committed to its development through case studies, 'explor[ing] and theoris[ing] the world through rich case studies' (Law and Singleton, 2013: 485), and other prominent and early laboratory (case) studies were conducted by Knorr-Cetina (1981), Lynch (1991) and Zenzen and Restivo (1982).

The sociologist Law began the trend towards that which is now distinguished from earlier constructions as After-ANT or Post-ANT (Law, 1999). Michael (2017: 120) suggests that post-ANT can be attached to performativity and what has been called the 'ontological turn', that is, turning 'attentions towards how reality is made or enacted' - a position also held by Woolgar and Lezaun (2015). Law (2009) shies away from calling ANT a theory, instead characterising it as 'a disparate family of… tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located. It assumes that nothing has reality or form outside the enactments of those relations' (Law, 2009: 141). Law and Singleton (2013: 486 – 489) similarly assert that ANT 'does not pre-exist, waiting to be applied. Instead it is created, recreated, explored and tinkered with in particular research practices… ANT is best treated as sensibility, as a craft or a set of practices that works slowly both on and in the world, as uncertain, as empirically sensitive, as situated'. Blok, Farias and Roberts (2019: xxii) term ANT an 'open-ended intellectual project', and Baiocchi, Graizbord and Rodríguez-Muñiz (2013: 324), '…a set of sensibilities, a disposition, or an attitude—rather than a rigid framework'. It is an 'inspirational frame [rather] than a constraining theoretical system' (Callon, 2001: 65). Indeed, Nimmo (2016: xxi) reinforces that ANT is not a theory, but rather 'an ontological-methodological formation'. In *Revisiting Actor-Network Theory in Education*, Fenwick and Edwards (2018: 2) describe it as the following:

> "ANT approaches examine how heterogeneous elements come together, and how they sustain or even cement their interrelations to form 'assemblages' that make

> things happen… ANT researchers examine how these material-and-social relations are negotiated, fortified, changed, dissolved, etc."

Post-ANT allows for less tangible objects, such as learning, to be seen as emerging as effects of the networks in which they are located, where assemblages are 'open, transient, unique networks or associations… An assemblage is not a thing, but a coming together of influences' (Elder-Vass, 2019).[24]

However, ANT is difficult to grasp and 'pin-down' particularly due to its multiplicity – it is built through, and consists of, a wide variety of studies across a number of disciplinary fields. Different 'disciplinary translations' of ANT include within geography and climate research (e.g. Whatmore, 2013; Bruine de Bruin and Granger Morgan, 2019), economics and markets (e.g. Barry and Slater, 2002; Callon, 2007), information systems (e.g. Tatnall and Gilding, 1999) and clinical practice (e.g. Mol, 2002), such as Olson (2009) who draws from ANT to study robotic surgery, Cresswell, Worth and Sheikh (2010) who employ ANT to explore IT implementation in healthcare, and Moreira (2006) who looks at coordination of blood pressure in neurosurgery. 'ANT is constantly fragmenting… a heterogeneous formation rather than something solid or definite', explains Nimmo (2016: xxii), continuing that that is partly driven by 'its circulation within multiple disciplines'. ANT is an open, continually moving 'building site', rather than a finished and closed construction (Law and Hassard, 1999). It is therefore key to maintain throughout this discussion that, although it may appear to be presented as such, it is not, and never has been, a unified approach (Rimpiläinen, 2012).

ANT frameworks and 'conceptual rigging'

ANT studies 'how relations assemble, or do not' (Law, 2009: 142), offering 'an array of practices for approaching complexity in the world' (Fenwick and Edwards, 2010: 8), and a 'rich array of explorative and experimental ways of attuning to the world' (Mol, 2010:

[24] Assemblages are also used in 'assemblage theory' (Deleuze and Guattari, 1980), which shares some similarities with ANT (Müller and Schurr, 2016).

265).[25] The framework is particularly suited for mapping the socio-material practices happening within a network in order to understand processes of innovation and knowledge creation in science and technology, looking at *how* things happen, rather than *why* (Latour, 2005; Fenwick and Edwards, 2010; Thompson and Rimpiläinen, 2012; Callon, 2012).[26] It is flexible and more importantly, empirically-grounded, promoting a theoretically-informed empiricism (Deleuze and Parnet, 2007). In order to understand, and work with, the complex approach more easily, I draw from four central principles of ANT: (1) heterogeneous networks; (2) generalised symmetry; (3) black boxing; and (4) translation. I will explain each principle briefly below (as these shall be re-visited in the Methodology chapter), since they have helped me to understand the complexities and multiplicities of ANT when constructing my research question.

The principle of heterogeneous networks: Heterogeneity signifies the ANT commitment to viewing the world as composed of a variety of elements, including technologies and humans, for example. Networks consist of heterogeneous participants, evident from the intertwinement of human and non-human actors and objects. This principle sometimes emphasises the difference between intermediaries and mediators in a network; the former is a mere carrier of information, whereas mediators transform, distort and modify what they carry. However, I am sceptical of the utility of these terms, and found them to be ANT 'baggage', cumbersome on my data collection and analysis, and as such only use 'actor'. Furthermore, ANT argues that practices are the result of a process of 'heterogeneous engineering' in which 'bits and pieces from the social, the technical, the

[25] Ideas around 'complexity' have become a cornerstone of interdisciplinarity (Newell, 2001; Welch, 2011), and this is similar to Donaldson, Ward and Bradley's (2010) use of the metaphor of 'mess' to explore the phenomenon. 'Mess is a feature of interdisciplinary research both because it is a feature of all research and because the objects around which interdisciplinary research is oriented are constructed and articulated through multiple research practices' (Donaldson, Ward and Bradley, 2010: 1526).

[26] Network is a concept for ANT, not a thing 'out there' (Baron and Gomez, 2016: 137). 'It is a tool to help describe something, not what is being described…' (Latour, 2005: 131).

conceptual, and the textual are fitted together' (Law, 1992: 380).[27] Oliver (2011: 379) explains that "the idea of heterogeneity refers to the 'bits and pieces', which might include people, technologies, materials, processes, and so on". This will help my research move away from conventional, reductionist and human-centric conceptualisations of interdisciplinarity, as well as technologically-deterministic approaches to technology projects, towards a framing in which 'humans are not assumed to have a privileged a priori status in the world but to be part of it' (Fenwick and Edwards, 2010: 3).

The principle of generalised symmetry: The principle of generalised symmetry attributes the potential for agency to non-humans (including technologies) as well as humans, emphasising the importance of applying common analytic tools. 'In actor-network webs the distinction between human and non-human is of little initial analytical importance: people are relational effects that include both the human and the non-human…' (Law, 2009: 147). It stresses the role which non-humans or objects play in networks by ensuring not to privilege humans as the sole 'source of action' in a network. It also begins to focus on practices, where practices are 'assemblages' in which 'bodies, discourses, technologies, objects, and so on are brought together to perform or enact a particular reality' (Michael, 2017: 121). Furthermore, a subject's agency, whether human or non-human, is understood as de-centred and an effect of the networked relations in which it is located (Callon, 1986; Sayes, 2014). 'The agency of nonhumans enables the agency of humans which enables the agency of nonhumans and so on' (Michael, 2017: 69). This principle is often mistaken to suggest that there is a direct symmetry between the agency of humans and non-humans, and the criticisms which follow from this are discussed below.

[27] Through an account of the 'failure' to produce an electric car (VEL) in France, Callon (2012: 77) also argues that 'engineers who elaborate a new technology as well as all those who participate at one time or another in its design, development, and diffusion constantly construct hypotheses and forms of argument that pull these participants into the field of sociological analysis… engineer-sociologists'.

Black boxing: Some objects (sometimes termed actants) can be understood as 'black boxes' (Bijker, Hughes and Pinch, 1987: 8).[28] Black boxes traditionally contain that which does not need to be considered, and a black box can be used in place of a piece of technology which is too complex to understand, about which nothing is 'important' apart from its input and output. If it is deemed to 'fail' – or, I believe, even if it is a success - it can be 'opened up' to see how it (should have) worked. Thus, an object – for example, the technology which was black boxed (or, 'punctualised') - can be understood as another heterogeneous network of actors in-and-of-itself. This is an important idea for studying technology in my research, as it will allow me to investigate emerging technologies, focussing on new technologies during their development before they become black boxed. As Latour (1987: 258) argues, 'we study science in action… to do so, we [can] arrive before the facts and the machines are black boxed'.

The principle of translation: 'To translate is to redefine another's interests or identity… Through translation, actors become enrolled into an actor-network', explains Michael (2017: 164) - where an actor-network is that which emerges with the 'successful alignment' of elements, but is in a 'constant churn of forming, staying together, or breaking apart' (Thompson and Rimpiläinen, 2012: 2). The relations that configure an actor-network are thought to constitute an 'arrangement of priorities' (Star, 1995: 89) - a snapshot of the social relations corresponding to the distribution of power at a given moment in time (Massey, 1991: 28). Lezaun (2017: 4) describes translation [a term borrowed from Serres (1974)] as 'an act of invention that operates by joining previously disparate elements'. The principle of translation can help me as the researcher understand how things 'come together' – and manage to hold together – however temporarily (Fenwick and Edwards, 2010).[29] Baiocchi, Graizbord and Rodríguez-Muñiz (2013: 330)

[28] It is important to note here that I do not borrow the word 'actant' in my own translation of ANT, since I am sceptical of its utility, unnecessarily complicating accounts of actors' distributed agencies.

[29] Barry (2013: 414 - 415) explains that the concept of translation has three senses in Actor-Network Theory: (1) political: a form of exercise of power, for example, within shifting and

add that '…as with other ANT concepts (and the meaning of ANT itself), its definition is slippery and has received different accents by different authors and at different moments in ANT's life course'. "Actors have their interests translated… and their relations reconfigured, and as such they are locally 're-made' as individuals" (Michael, 2017: 22). Callon (1986), in his paper *Domestication of Scallops and the Fishermen of St. Brieuc Bay*, suggests four key 'moments' of translation, which will become central to the construction of the narrative throughout this study:

(i) Problematisation: The definition of a 'problem';

(ii) Interessement: Practices that an actor employs to impose (and stabilise) particular roles, identities and interests on other actors;

(iii) Enrolment: The 'successful' placing and acceptance of certain entities into designated roles, to coordinate 'appropriately' within a network;

(iv) Mobilisation: A spokesperson can represent the network externally, 'when the network becomes sufficiently durable that its translations are extended to other locations and domains' (Fenwick and Edwards, 2010: 14).

These stages can follow actions by any entity which attempts 'to impose and stabilise the identity of the other actors' (Callon, 1986: 8). ANT thus explores the ties within a network, examining how things get their meaning in relation to others. It offers a means of mapping not only the social and material relations, but also those that are conceptual – crucial for contexts where competing research approaches, disciplinary methodologies and theories are continuously negotiated, for instance, within interdisciplinary research projects developing new technologies. The four moments of translation will be important during both conceptual and methodological design, and empirical data collection.

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contested spaces of scientific and technical practice; (2) geographical: movement in, and the transformation of, space; (3) literary: a process of replication *and* differentiation at the same time. My conceptual and methodological use of 'translation' aligns more closely, although not exclusively, with the 'political' aspect.

It is important to note at this point that I frame my use of ANT alongside that of Mol (2002), Fenwick and Edwards (2010) and Rimpiläinen (2012). Like them, I acknowledge the diversity of ANT and use it as a 'temporary marker' to refer to a 'constellation of ideas' (Thompson and Rimpiläinen, 2012: 2). This is close, but not absolutely equivalent, to the *Post-ANT* tradition. Each study enacts ANT differently, and although I use the term ANT throughout, I do not wish to bundle it too closely with the plethora of associations garnered through the years. Fenwick and Edwards (2010) use the term ANT as a 'tentative organiser' – a way to refer to a cloud that in fact escapes any attempt to grasp it – and this too is my approach throughout this study. We both follow Law's (2002) cautions about not getting caught up in what is a 'real' account of ANT and what should and should not be included. Studies 'bend and twist ANT' to address the research questions at hand, and this too is how I draw from the approach.

Criticisms and responses

ANT is all at once complex, controversial and difficult to define. Despite a number of overviews and volumes of the topic, including Nimmo (2016), Michael (2017), Repko, Szostak and Buchberger (2017), Lezaun (2017) and most recently, Blok, Farias and Roberts (2019), 'it is extraordinarily difficult to write or talk about actor–network theory without either destroying or domesticating it' (Fenwick and Edwards, 2010: 1).[30] Latour (1996) wrote *On actor-network theory: A few clarifications* in particular to deal with some early mis-understandings of the 'framework', and ANT researchers often feel strongly about how the framing is interpreted and put into practice.

One of the most prominent criticisms of the approach is surrounding its perceived insistence on 'generalised symmetry', that humans are assigned the same agency as non-humans. However, this point is often taken too literally; for instance, Sørensen (2009) takes this symmetry to extremes through assuming asymmetry. I must therefore ensure

[30] I found Mike Michael's (2017) *Actor-Network Theory: Trials, Trails and Translations* also very helpful for getting to grips with terms such as 'assemblage' (an array of connections of heterogeneous elements).

that I do not do the same within my study, and rather, I plan to approach my participants without assuming direct symmetry, but instead remaining open to the possibility that asymmetries may occur between researchers and technologies-in-development (Rimpiläinen, 2012). It is also argued that while ANT seeks to view actors as continually emerging effects of webs of networked relations within which they are located, many ANT studies still appear to take actors as existing 'out there' with inherent properties (Rimpiläinen, 2012; Whittle and Spicer, 2008). However, it is crucial to note that ANT does not explicitly say that there is no distinction, just that it shouldn't be taken as a given. Indeed, Sayes (2014: 144), in clarifying 'what it means' to suggest that non-humans have agency, points out that 'nonhumans do not have agency *by themselves*, if only because they are *never* by themselves'.

Furthermore, Hassard and Alcadipani (2010: 10) criticise Callon's four moments for being a 'recipe', 'instead of being thoroughly and richly explained, a variety of specific organising processes are described in a nice and tidy way, thus oversimplifying what needs to be explained'. I will try to negate this through a richness of narrative in my Findings chapters. Potentially most problematically, however, many scholars – including Callon and Latour – now disagree with the label 'Actor-Network Theory', since it focusses on how networks are formed and sustained, rather than theorising why a network takes the form it does. Law (2009) suggests 'material-semiotic method' would better reflect how ANT maps relations that are simultaneously material and semiotic, but for the sake of this study it will not be productive to dwell on semantics.

In light of these potential criticisms, Cultural-Historical Activity Theory (CHAT), which builds on Vygotsky's mediated view of action (Kuutti, 1996), could frame this study well since at its core, technology is understood in terms of its ability to mediate action. There is a high volume of case-based research in the field, and like ANT, it considers the network as a 'holistic unit of analysis' (Oliver, 2011: 379). However, it is not suitable for my research since not only does CHAT focus on the *use* of technology within a cultural and

historical context (Barab, Schatz and Scheckler, 2004), it also differentiates between the object, subject and tool as end-result and process, whilst assuming that the mediator is always material (Engeström, 1987). Indeed, Langemeyer and Roth (2006) argue that CHAT oversimplifies the complexities of social interaction, and I must be sensitive to the complexities of relations in interdisciplinary research. ANT, on the other hand, allows for entities such as disciplinary knowledge concepts and interdisciplinary methodologies to be included. Nevertheless, Miettinen (1999: 171) argues that 'ANT formulated a general methodological maxim that seemed to me both interesting and complementary to CHAT itself', continuing, 'Follow the actors, both as they attempt to transform society and as they seek to build scientific knowledge or technological systems'.

'Communities of Practice' (Lave and Wenger, 1991; Wenger, 1998) might also constitute a suitable theoretical framing, since it can frame how technology and practice are related (e.g. Smithson, Hennessy and Means, 2012). However, this would focus the lens on situated learning, which is potentially only one aspect of interdisciplinarity in practice. Likewise, computer-supported collaborative learning (CSCL), building upon Vygotsky's (1978) work in which processes of knowledge-building are identified through group interactions, is not a suitable framework through which to examine technology mediation within interdisciplinarity. This is primarily due to the focus of this study on technologies-in-development (as already established), rather than ICTs used for organisational, communication and facilitation purposes (Stahl, 2005; Scardamalia and Bereiter, 2006; Stahl, Koschmann and Suthers, 2006).

ANT in the field of Education

An early contribution by Nespor (1994), studying the differences in behaviour between Physics and Business University students, brought STS to the attention of educational researchers. A later study by Gorur (2011), tracing how PISA knowledge comes to be

made, among others, began to sensitise ANT as an accepted approach within the field.[31] As Gorur et al. (2019: 6) argue, 'now, perhaps more than ever before, STS is needed to make sense of… the unique pressures facing the field of education', continuing, 'the knowledge practices and political practices of education provide good grounds for STS and ANT research' (Gorur et al., 2019: 11).

Indeed, Sørensen (2009), reflecting on her empirical studies into initiatives to introduce online environments into Danish and Swedish classrooms, in which she conceptualised learning as socio-material rather than strictly social, argues that – as I have found in studies of interdisciplinarity - the general omission of materiality in educational studies has created serious limitations. '[What is] material is often taken to be the background context against which educational practice takes place or within which it sits, and material artefacts are often taken to be simply tools that humans use or objects they investigate' (Fenwick, Edwards, and Sawchuk, 2011: 1). Indeed, as I have established, 'education remains almost inherently humancentric by definition…yet socio-material studies suggest the need for us to at least problematise such a focus, if we want to do worthwhile educational work' (Fenwick and Edwards, 2018: 15). It is important to de-centre the human in educational research, and thus I will frame my research question as such, moving away from traditionally human-centred approaches to (technologically-mediated) interdisciplinarity in Higher Education.[32] 'Sociomaterial researchers in education are gradually creating an in-between place of sociomaterial/STS studies and education, and showing this to be an important area of inquiry', explain Fenwick and Landri (2014: 3).

[31] I have found Fenwick and Edwards (2010) *Actor-Network Theory in Education*, and their more recent *Revisiting Actor-Network Theory in Education* in 2018, particularly enlightening.
[32] 'Education and educational things in an ANT approach are… not seen as pre-existing objects of enquiry, but as emerging through enactments of various forms of association, as network effects', explain Fenwick and Landri (2014: 2).

2.2.3 How is (interdisciplinary) knowledge construed within ANT? The practice of knowing

Research is understood to be in-part about the generation of new knowledge. Through the *Harvard Interdisciplinary Studies Project*, a study of research and teaching practices in interdisciplinary institutes and programmes across the USA (aiming to inform educational practices that foster interdisciplinary understanding), Mansilla and Gardner (2003) note that interdisciplinary research is a pervasive form of knowledge creation. ANT provides a useful framework through which to shed light on this process, and through which to build upon existing conceptions of disciplinary (and thus interdisciplinary) knowledge-building as discussed previously. Knowledge is not about representing things 'as they are'; it emerges from transactions and subsequent reflections, and is therefore simultaneously a construct and *of* the 'real' world (Biesta, 2009; Fenwick and Edwards, 2010). 'All knowledge and all knowledge-claims are to be treated as being socially constructed' (Bijker and Pinch, 2012: 401), and Pea (1993) explains how knowledge is co-constructed through collaborative efforts towards shared objectives, for example, shared research questions. 'Practices of knowing are specific material arrangements that participate in (re)configuring the world… Making knowledge is not simply about making facts but about making worlds', argues Barad (2007: 91). In (interdisciplinary) research, this suggests there are thus multiple realities, multiple perspectives, multiple epistemologies and most importantly, multiple ontologies produced through the research processes, as will be discussed further below (Law; 2004; Mol, 2002). 'A thing can be enacted through multiple knowings or ontologies that co-exist', explain Fenwick and Edwards (2010: 35). New (interdisciplinary) knowledge can be co-produced through the negotiation of different (disciplinary) ontologies (that is, what 'exists' for someone or something, at a time). For example, Enriquez (2009) studies how the virtual learning environment (VLE) Blackboard 'enacts multiple ways of working' as it is used in different departments, and Latour and Woolgar (1979) discuss how in a laboratory, there can be 'controversies' around the different and competing realities.

ANT can be used to explore how knowledge is 'enacted as a network effect' of a web of relations (Thompson and Rimpiläinen, 2012), since as well as technology, it can emerge from a heterogeneous (interdisciplinary) network (Rimpiläinen, 2012: 47), and may take material forms (Law, 2004). Yet 'this interplay of force relations among technology, things and changes in knowledge at every point in the network is a continuing struggle', suggest Fenwick and Edwards (2010: 9). Knowledge production is situated and distributed, and 'knowing' is an action; it is performative, and something we 'do'. It is a knowledge-centred epistemic practice (Knorr-Cetina, 1999):

> "Professional practices of knowing are becoming more complex and fluid; comprised of an interconnected array of people, ideas, technologies, and other objects… sociomaterial sensibilities suggest that it takes both human and nonhuman actors to enact any practice. Knowing and knowledge practices entail a mishmash of entanglements, alliances, resistances, and willing partnerships between such actors. The fusion of work and knowledge mobilization activities… and the momentary coalescing of ideas, people, and technologies that generate or sustain professional practices produce phenomena that are challenging to study. Yet, embracing such ambiguities and starting from the 'uncertainties and controversies about who and what is acting when 'we' act' (Latour, 2005, p. 45), creates expansive openings for the researcher." (Thompson and Rimpiläinen, 2012: 1)

2.2.4 The practice of interdisciplinary knowing in Higher Education

Despite the pervasive silos, as already established, the University can be a hub for interdisciplinary knowledge production.[33] Interdisciplinary research in Higher Education has to do with the production of new knowledge (Delanty, 2001), and multiple 'knowledges' co-exist across the disciplinary spectrum. While there is no universally

[33] 'Academic practices are the clusters of social practices that occur in higher education that are concerned, directly or indirectly, with the production, reproduction, circulation and use of knowledge in different forms' (Trowler, Saunders and Bamber, 2012: 15).

shared definition or conceptualisation of what knowledge is across the disciplines, 'every research approach is based on some assumptions about the nature of reality (ontology) and what kinds of knowledge claims can be made about it (epistemology)' (Rimpiläinen, 2012: 17). Mulcahy (2013: 10) argues that interdisciplinary knowledge can emerge from connections between disciplinary knowledges, 'materialised… in a variety of forms and relations… [which] coexist… Interdisciplinary knowledge work in Higher Education involves occupying the space between disciplines, knowledges and methodological orientations and cultivating its unknown potential'. There are two important things to note here. Firstly, the new knowledge of which Delanty (2001) talks must be obtained through methods that pertain to certain validity and reliability requirements within each of the disciplines' ontological standpoints (Brew, 2007). Secondly, and more importantly, knowledge, as well as other research outcomes, is an emergent product of the scholarly research process - rather than something that exists 'out-there', waiting to be discovered.

If new forms of knowledge co-creation happen in interdisciplinarity, then we need to know how they happen. Knowledge and technology are increasingly bound up, and it is nearly impossible to separate the two in research. It could thus be interesting to explore nascent ideas that new knowledge could be embedded in new technologies, proposed by Strathern (2004: 18) who argues that technology can be 'know-how embedded in the artefact' and Pea (1993) who explains that intelligence can exist in designed artefacts. This area is ripe for further exploration.

2.2.5 ANT and technologically-mediated interdisciplinarity: moving from perspectives to realities

It has been suggested that 'ANT offers numerous insights for those pursuing [studies of] interdisciplinar[ity]' across a number of fields (McMurtry, 2013: 93), but only a very small number of studies have explicitly done this. For example, Balmaceda et al. (2019) look at energy materiality; Wallsten (2017) engages Callon's (1986) four moments of translation to follow the construction of a smart grid; and Wong (2016) looks at interdisciplinary

energy research through an ANT frame. Wong (2016: 109) draws from ANT as a 'mode of thinking' about interdisciplinary energy research, suggesting that concepts including heterogeneity, enactment and translation 'can help frame the research problem in a way that could pull together previously divergent/distinct researchers, concepts, devices and data'. Additionally, Lin (2012: 1) investigates the 'socio-technical challenges of digital humanity emerging in the shift towards trans-disciplinarity' through an 18-month ethnographic case study of an interdisciplinary project. Furthermore, in her ethnographic case-study of research and development practices in an interdisciplinary project between education and computer sciences, Rimpiläinen (2012) not only sought to understand how a shared research question is answered in practice when divergent research approaches are brought to bear upon it, but also to assess the advantages and disadvantages of Actor-Network Theory (ANT) as a theoretical practice. There is productive space to build upon this study and work with ANT in order to investigate the complexities of social-material practices of technologically-mediated interdisciplinarity in Higher Education.

Drawing primarily from approaches which align most closely with the *post-ANT* tradition, and understanding the tradition as a 'mutable mobile' (de Laet and Mol, 2000),[34] that is, one which is malleable and 'fluid', certain ideas from this 'school' will be particularly useful for investigating interdisciplinary research practices in this thesis. A number of writers from the *post-ANT* tradition, most prominently Mol (2002, 2010), have put forward that (scientific) research does not simply represent its objects, but actually generates new entities. According to this logic, and as previously suggested, research practices therefore 'enact the world', and Mol (2002) argues, simply yet counterintuitively, that each practice generates its own reality. In parallel, as has been established throughout this literature review, it is commonplace to assume that interdisciplinarity is about 'managing diverse perspectives or even reconciling them.

[34] de Laet and Mol (2000) focus on the 'fluidity' of a bush pump in Zimbabwe; while the bush pump in question is itself solid and mechanical, they argue that its boundaries are 'vague and moving'.

[However] the recent ANT switch to understand educational practices as multiple simultaneous ontologies opens a rich new approach [to studying and understanding phenomena]' (Fenwick and Edwards, 2010: 159). 'Much interdisciplinary research seems to proceed from the assumption that synthesis is desirable, that a new integrated perspective can be found on a singular object' continue Donaldson, Ward and Bradley (2010: 1534), adding that 'the ontological view [on the other hand]… holds that the objects of interdisciplinary research are, almost by definition, anything but singular'.

In *The Body Multiple*, Mol (2002) follows conceptions of atherosclerosis through a Dutch university hospital, focussing on practice as the unit of analysis, and discussing 'multiple ontologies' through the example of the disease, exploring how they become enacted in different ways as a part of different diagnostic practices. Mol's (2002: 54) argument is that by being enacted through different practices, the disease multiplies, becoming 'more than one', while simultaneously hanging together through associations that travel between the different practices. Firstly, Mol's (2002) study has guided my attention to the practice (the 'doing') of research and technology development. Secondly, I follow Mol (2002) in her focus on ontologies – where ontologies are not 'given in the order of things… [but] brought into being, sustained, or allowed to wither away in common, day-to-day, sociomaterial practices' (Mol, 2002: 6).[35] This is a move from an 'epistemological approach, that sees mess as a result of different perspectives on a singular object, [towards] the ontological approach, which sees mess as a result of the multiplicity of objects' (Donaldson, Ward and Bradley, 2010: 1531).[36] For Mol (1999, 2002) and Law and Lien (2012), practices enact realities, and therefore different practices, or 'enactments', generate different realities, or 'ontologies'. This ontological multiplicity lies at the heart of

[35] It is important to note that, like McMurtry (2013), I do not agree that epistemological and ontological concerns should be considered as *entirely* separate, but as *distinct*.
[36] Sometimes the best way to tackle the mess of an interdisciplinary object is to acknowledge its multiplicity and not try to reduce that through synthesis', argue Donaldson, Ward and Bradley (2010: 1533 – 1534). Yet, as has been established, the 'conventional' or 'traditional' discourse on interdisciplinarity does not, on the whole, acknowledge the 'mess' inherent in (technologically-mediated) interdisciplinary research.

what Mol terms 'ontological politics',[37] which directs attention towards the way certain socio-material arrangements perform their own realities. As Nimmo (2016: xxxvi) explains:

> "This is also a theory of multiplicity, since it involves the contention that realities – as enactments embedded in particular practices – are always local and multiple; hence realities co-exist and overlap, and can also be in tension with one another… [which] becomes a political matter, a matter of 'ontological politics'"

Thus, in studying interdisciplinary research, the epistemological approach broadly assumes that there is a single object, with multiple perspectives, of the research object associated with different disciplinary viewpoints. In contrast, the ontological approach assumes multiple (overlapping) objects, since these objects cannot be entirely separated from the different disciplinary practices that engage with them. Donaldson, Ward and Bradley (2010: 1526) reflect upon Law and Singleton's (2005) explanations of this move from epistemologies towards ontologies, through an interdisciplinary lens:

> "Law and Singleton (2005) have suggested that we can take two different approaches to dealing with messy objects: epistemological or ontological. An epistemological approach presumes that an object looks messy because there are different perspectives on it, and so it means different things to different people…. The literature on interdisciplinarity… can be seen as just such a response - different schema and typologies have been generated to pin down the reality of interdisciplinarity… The ontological approach suggested by Law and Singleton presumes that there is not always a stable underlying reality and that objects are multiple: rather than different perspectives there are various sets of practices which articulate different, though interrelated, objects (Law and Singleton, 2005; following Mol, 2002)"

[37] For Mol (2002), the advantage of the word 'enactment' is that it does not connote a central 'performer' behind the reality that is being constructed.

This means a move from a plurality of worldviews (as traditional conceptions of interdisciplinarity treat the phenomenon, as presented above) to a plurality of worlds; from multiple (interdisciplinary) perspectives to multiple (interdisciplinary) realities – interconnected realities. 'Different disciplines' divergent practices… yield divergent ontologies', explains Michael (2017: 125), and Barry, Born and Weszkalnys (2008) argue that ontological plurality can be more generative than integration. Such insights suggest that critical reflection on interdisciplinarity is extremely valuable, and ANT sensibilities can help me attend to, attune to, and interfere with processes of (un)settling differently enacted realities in technologically-mediated interdisciplinary research projects in Higher Education.

2.3 Summary and Research Question

My study aims to reframe the 'traditional' discourse on technologically-mediated interdisciplinarity, largely permeated by social explanations and 'tropes', and technologically deterministic studies, to concerns around the emergence of socio-material practices of interdisciplinarity. New insights are needed into aspects of how interdisciplinary research 'happens' in Higher Education, and ANT can attune well to interdisciplinarity as the object of study. ANT offers the potential to delineate the tensions which exist in current research, privileging neither the human nor the technology, in order to generate more critical conceptual framings of interdisciplinary research in technology projects, particularly within US Higher Education (taking into account the complexities and material participations inherent in interdisciplinarity). This research aims to build upon and contribute to the existing body of knowledge around interdisciplinarity and technology, and to the application of ANT in Education. Drawing together ideas from the literature on interdisciplinarity *and* ANT, conceptualising interdisciplinary knowledge work as performative practice, and as a 'matter of concern', I will next describe the methodology of this study. This thesis is an exploration of how heterogeneous research teams (both human and non-human) enact interdisciplinarity 'in-the-making' (Mattila,

2005: 16). Attending to the 'plasma' of interdisciplinarity (Latour, 2012: 93; Callard and Fitzgerald, 2015), this thesis aims to make visible technologically-mediated interdisciplinarity 'in practice'. As such, the central research question of this study asks:

How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?

CHAPTER 3: METHODOLOGY

Introduction

In this chapter I present my research design and methodological framework for studying technologically-mediated interdisciplinary research practices in Higher Education. As discussed, Actor-Network Theory (ANT) offers a valuable framing for interrogating the 'unity of interdisciplinarity' (Barry and Born, 2013: 5) as it unfolds and comes to be enacted. Importantly, it can account for the heterogeneity of participants and relations by acknowledging the 'mess' inherent in studying interdisciplinary researchers, concepts and technologies. I have argued that novel methodological and theoretical development is necessary to generate new insights into how interdisciplinarity 'happens' in Higher Education. Having recognised the need to move away from 'grand narratives' of interdisciplinarity (Welch, 2011: 32), including deterministic conceptualisations of the phenomenon, towards a more critical framing, and presented the theoretical foundations through which to do so, I now discuss the methodological approach taken in this thesis.

First, I will briefly re-visit how I engage with ANT in order to attune to emergent, technologically-mediated interdisciplinarity as the object of my empirical study. Drawing on ANT as a conceptual, theoretical and methodological practice, I explain how this framing helped to define my research question, and how to address it in practice, as well as shaping this thesis design more broadly.

Second, I will explain my rationale in choosing a 'praxiographical' ethnographic collective case study through which to accomplish the empirical investigation, following three research projects in real-time as they move from research questions to emerging technological outcomes. I will explain how my initial research designs were refined during this.

Third, I will present a detailed description of the empirical setting, including the specific choices made when navigating access to the field; the methods of data collection and

analyses I adopted; and the narrative approaches and ethical considerations in which I engaged in order to attend to the depth, heterogeneity and complexity of technologically-mediated interdisciplinarity 'in-the-making' as laid out in the study's core research question. My methodology reframes 'conventional' questions of interdisciplinarity, to questions concerning the emergence of socio-material practices within interdisciplinarity.

3.1 Actor-Network Theory (ANT) in practice: attuning to technologically-mediated interdisciplinarity as an object of study

3.1.1 Key methodological concepts drawn from ANT

Actor-Network Theory (ANT) was introduced and discussed in the previous chapter, but a few concepts must be re-visited in order to more closely explore its methodological propensities. ANT studies 'how relations assemble, or do not' (Law, 2009: 142), offering an empirically-grounded 'array of practices for approaching complexity in the world' (Fenwick and Edwards, 2010: 8). Law (2009: 141) characterises ANT as 'a disparate family of… tools, sensibilities and methods of analysis that treat everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located,' and Law and Singleton (2013: 486 – 489) similarly assert that ANT 'does not pre-exist, waiting to be applied. Instead it is created, recreated, explored and tinkered with in particular research practices… ANT is best treated as sensibility, as a craft or a set of practices that works slowly both on and in the world, as uncertain, as empirically sensitive, as situated'. In other words, ANT is not simply 'applied', but is rather tested, adapted, or even discarded. 'It should be adjusted in response to the experience of empirical research', explains Barry (2013: 418).

But being characterised as a 'sensibility', rather than a theory or a methodology, ANT is 'notoriously vague in terms of methods' (Rimpiläinen, 2010:1). 'Unlike more conventional approaches there is a notable lack of detail, description or direction around methods for ANT investigations. While there are often rich accounts of fieldwork and thick description of scenes, how these were selected or connected is not spelled out' explains Wright (2016:

12). And even if various characterisations of ANT might frame it as a method, 'there are very few attempts that try to spell out how in practice to carry out such research' (Rimpiläinen, 2012: 42). Indeed, 'it is often easier to talk about these concepts than to apply them to one's own research questions, methodology, and data', suggest Thompson and Rimpiläinen (2012: 1). Through explanation of the role of ANT in the methodological practices of this study, as laid out in this chapter, I seek to address these concerns, and thus offer methodological contributions for the application of ANT in Education.

Despite the criticisms, just as 'the ANT tradition offers a large repertoire of methods for analysing the distributed, heterogeneous, and emergent features of social phenomena such as design practice' (vu Henry, 2018: 80), so can the tradition offer methodological contributions to investigating technologically-mediated interdisciplinary practice. For example, McDougall et al. (2016) study interprofessional medical teams through ANT, and Wong (2016: 109) uses ANT as a 'mode of thinking' about interdisciplinary energy research, suggesting that concepts including material-semiotic heterogeneity, enactment, and translation 'can help frame the research problem in a way that could pull together previously divergent/distinct researchers, concepts, devices and data'. I similarly argue that engaging ANT can help to maintain some degree of conceptual consistency when attending to different disciplines, and disciplinary assemblages, that may bring with them different (and often conflicting) ontologies. Once I had become accustomed to navigating the flexibility and diversity of ANT, I found that the following principles in particular helped me to attend to the study's central research question.[38]

Generalised symmetry

'The field of educational research lacks a methodology… that does not begin with humans, their aims, and their interests,' argues Sørensen (2009: i). This is thus the case for looking at interdisciplinarity through educational research, and therefore gives space for valuable

[38] These could be understood as 'core' principles which can begin to help ANT researchers become more methodologically rigorous.

contributions in this area. The principle of generalised symmetry (Callon, 1986), which, as previously presented, attributes the potential for agency to non-humans as well as humans, offers some 'theoretical rigging' to foreground technologies, concepts, interdisciplinary methodologies, and other objects, in tackling my research question. The concept prompts researchers '…to move beyond characterisations of interdisciplinarity… based either on the social or the natural' (McMurtry, 2013: 93). This, in particular, helps me deviate from the socially deterministic definitions of interdisciplinarity which permeate modern thought. This principle reminds researchers in this area to be as attentive to non-humans as humans, and is 'applied' in designing the methodological framework of this current study, choosing methods which can bring to the fore 'voices' of non-human actors as well.

Translation

Translation focusses on what happens at each of the connections between heterogeneous participants in a network, tracing how things 'come to be', or do not, and recognising that many of these are 'momentary' (stabilisations of) relations. This is particularly suitable for exploration of my research question since '…the method of tracing highly particular, moment-to-moment translations occurring among heterogeneous materials, [is] a way to understand technological innovation' (Fenwick and Edwards, 2010: 80). The principle of translation helped me to think about how interdisciplinarity might 'come together', hold together, or break apart (Fenwick and Edwards, 2010). Indeed, Cressman (2009: 10) '…encourage[s] further exploration into the concept of translation… The question what is being translated as opposed to studying the mechanisms of translation opens ANT to new lines of inquiry'. In conjunction, Callon's (1986) 'four moments of translation' helped me to think about the *moments* during translation when interdisciplinarity might be enacted, and Wallsten (2017) engages these four moments to track the configuration of a smart grid: 'the network builders…translated the original problem… into a solution' (Wallsten, 2017: 205). This 'structuring' of translation has been critical not only for the initial

methodological design of this study, but also the empirical data collection, analysis, and narrative structure of the thesis. As vu Henry (2018: 87) explains, this ANT concept '…provided useful parameters to constrain the scope of analysis into a feasible doctoral project and to organise [her] writing into a coherent…narrative'. Where I found the concept of translation somewhat methodologically ambiguous in terms of data collection, however, the next concept, 'following the actors', offered me a clearer methodological 'way-through' Callon's (1986) four moments.

'Following the actors' with analytical tokens

In order to put the principle of translation into practice in attending to technologically-mediated interdisciplinarity as an object of study, I took the analytic decision to 'follow the actors' (Adams and Thompson, 2011),[39] rather than to 'limit in advance the shape, size, heterogeneity, and combination of associations' (Latour, 2005: 11). In practice, this meant that I 'took' my inquiry wherever the actors - technologies-in-the-making, research papers or researchers, for example – led me, rather than setting strict 'boundaries' for the size and scope of my exploration before I began fieldwork (Fenwick and Edwards, 2018: 143). 'Much has been made of the invocation to follow the actors in conducting research with ANT' (Fenwick and Edwards, 2010: 14). Consistent with the methodological approach operationalised in Rimpiläinen's (2012) study of educational technology and vu Henry's (2018) study of design practice, I set out to present the findings as unfolding empirical narratives of interdisciplinary practices. By focussing on the *doing* of research and technology development, Rimpiläinen (2012) was able to trace the emergence of a piece of educational technology through the multiple, at times competing and conflicting, disciplinary practices. Like Mol (2002), I 'follow[ed] the actors wherever they [led me]' in order to answer the research question (Callon and Law, 1982: 284). Yet Latour (2005: 121-122) muses:

[39] 'Following the actors' is one of Adams and Thompson's (2011) heuristics to 'interview objects', as discussed below.

> "How ridiculous is it to claim that inquirers should 'follow the actors themselves', when the actors to be followed swarm in all directions like a bee's nest disturbed by a wayward child? Which actor should be chosen? Which one should be followed and for how long? And if each actor is made of another bee's nest swarming in all directions and it goes on indefinitely, then when the hell are we supposed to stop?"

Tackling these questions, I began to identify individual actors across the case studies which I had selected whose trajectories I should trace, by drawing on the concept of analytical tokens. Gaskell and Hepburn (1998) describe a token as a focal actor whose path is followed in order to trace an actor-network; this could be an object, discourse, concept, person, technology, or research question, for example (see sections 3.3 and 3.4 for how I engaged the concept to 'find a way through' my chosen methods). 'In the model of translation, not only the token is continuously transformed as links with other actors are established but so are other actors', Gaskell and Hepburn explain (1998: 66). I looked in particular for '…[actors] making other [actors] do things, human or nonhuman' (Latour, 2005: 217). The analytic task here was to determine 'entry points' into the complex webs formed through each research project, and then to carve out and characterise sets of actors most relevant to tracing enactments of technologically-mediated interdisciplinarity. I identified tokens in each interdisciplinary research project case study (see section 3.3.3), tracing patterns of connection or change during the processes of the teams moving from research problems to emerging technological outcomes (Harman, 2009: 44).[40]

3.1.2 A note on refining the research question

During the early stages of the literature review, I was formulating three initial questions. They asked:

[40] In particular I had methodological difficulty in defining the 'analytical tokens' in the Digital Humanities (CS2) and Energy (CS3) projects, and so I looked specifically for tokens that might enrol actors into the actor-network; the steerable needle in the case of the Medical Robotics project (CS1), for example.

- What is the relationship between emerging technologies and knowledge co-production in interdisciplinary research?
- How does taking part in technologically-mediated interdisciplinary practice influence the methodological perspectives of researchers?
- How are new technologies created during interdisciplinary research practices?

However, once I began fieldwork I quickly realised that these needed to be modified according to the application of ANT *in practice* to my empirical research.[41] For example, the idea of 'influence' in the initial research question 2 would not be conceptually interrogated through ANT. Thus, my central research question emerged as my data collection developed, more accurately attending to the 'generalised symmetry' of the human and non-human actors with whom I was becoming acquainted (Punch and Oancea, 2014; Miles and Huberman, 1994). The research question, as introduced above, became: How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?

'ANT influences the questions asked, the way you explore your phenomena, what is attended to, how you understand and think with your data, and how it might be represented' (Thompson and Rimpiläinen, 2012: 1). The phrasing of the research question (in the passive, without assuming who does the 'doing') is an attempt to work with the principle of generalised symmetry, freeing space for non-human actors to emerge as participants in the research and development processes alongside human actors. Indeed, Mol (2010: 261) suggests that '…if you link up with [ANT] you learn sensitising terms [and] ways of asking questions'.

[41] How, why, and during *which* moments, will be discussed throughout.

3.2 Methodological framework

3.2.1 Ethnography becomes 'praxiography'

The choice to use ethnographic research methods arose from close attention to the research question since '…decisions about design, data collection and analysis should stem from a consideration of research questions' (White, 2013: 224). Given the nature of the research problem, it was clear that an ethnographic approach would be used. Ethnography allows a researcher to approach a topic without any preconceived theoretical constructs in mind (Hammersley, 2007), and thus to see the 'messiness of practice', looking '…to try to understand the often ragged ways in which knowledge is produced in research' (Law, 2004: 18-19). Ethnography 'involves the ethnographer participating… in people's daily lives for an extended period of time, watching what happens, listening to what is said, asking questions – in fact collecting whatever data are available to throw light on the issues that are the focus of the research' (Hammersley and Atkinson, 1983: 1).

Ethnography is an established qualitative approach (Fetterman, 1998; Brewer, 2000; Hammersley and Atkinson, 2007), and there is a strong tradition of ethnography in the field of Science and Technology Studies (STS) (Haraway, 1991; Mol, 2002), as well as in ANT (Latour and Woolgar, 1979; Law, 2004). ANT, in particular, invites an ethnographic approach since this allows for multiple, complex and varied phenomena to emerge (Suchman, 2006), and Fenwick and Edwards (2010: 146) argue that 'what ANT brings to its ethnographic methodological approaches is a sensibility for mess and it attempts to suspend a priori assumptions'. Indeed, Whatmore (2003: 93) points out that an 'ethnographic approach produces qualitative description… well-suited for attending to configurations composed of humans and non-humans'. A 'classic' ethnography in STS is the aforementioned laboratory study by Latour and Woolgar (1979, 1986), who offer an account of 'doing science' at the Salk Institute in San Diego. Indeed, 'ethnographers go into the field these days to study scientific laboratories, businesses or… interdisciplinary research projects,' note Barry and Born (2013: 30).

I am interested in *practices*; that is, foregrounding the socio-material practices of technologically-mediated interdisciplinarity. 'A practice perspective attends to the role of artefacts in practice performance, to material mediation… As artefacts change, so do practices, but practices are also inscribed on artefact use', explains Trowler (2014: 21). The focus on 'practice' in the study's research question thus calls for a sensitivity to practices in the research methodology. 'Ethnography is a suitable method for studying practice, and for finding answers to open questions about the nature and formation of these practices,' writes Sørensen (2009: 3), continuing, '…doing an ethnography of new…technologies means studying them in practice'. Monteiro (2018: 167) adds that 'ethnography, inasmuch as it allows for a close embeddedness in an interdisciplinary setting, enabling the social scientist to become more fluent in the myriad epistemologies [and ontologies] at play, can produce unique understandings of how teams work in practice'.[42]

Moreover, Nimmo (2011: 113) explains that 'central to the commonalities between ANT and ethnography is a shared emphasis upon practices… Both eschew neat analytic categories in favour of a sensitivity to messiness, contingency and non-coherence; both acknowledge the heterogeneity of practices and their interweaving of the social and the material'. Yet, 'ethnographers in sociology have not made much use of ANT… this lack of engagement among sociologists is regrettable', comment Baiocchi, Graizbord and Rodríguez-Muñiz (2013: 326). Indeed, Mol (2002: 32) points to the utility of ethnography as a methodological instrument for studying practices, in which the ethnographer must be attentive to the 'ordering' of heterogeneous elements involved in socio-material practices in line with the principles of ANT. In *The Body Multiple*, while studying different diagnostic practices at a Dutch hospital, Mol (2002) suggests that complex day-to-day practices can be investigated using what she calls 'praxiography' as a research methodology. Praxiography employs the methods of ethnography to address the materiality of practice, focussing 'the ethnographer's lens… at the level of practice' (vu

[42] 'Take any practice. Ask about its choreography. Ask how it weaves its relations and enacts its objects' (Law and Lien, 2012: 371).

Henry, 2018: 69 - 70), and thus can provide a vehicle for engaging empirically with my research question, as well as with the conceptual underpinnings of ANT. It is 'a particular take on ethnography which sees the world in a specific way', suggests Trowler (2014: 18), continuing that, 'a praxiographic approach… privileges close up, in-depth, case study-based research designs of the ethnographic sort' (Trowler, 2014: 20). Whilst Mol's account does not specify the methods through which 'praxiographic' research should be undertaken, Oliver (2012: 443) explains that:

> '…the exploration is undertaken ethnographically; like actor-network theoretic studies (e.g. Latour & Woolgar, 1979) it involves following the actors, and uses observations, field notes and interviews to generate data. These sources are used to produce accounts of peoples' practices, and thus the ways in which they enact reality… While this approach was developed in order to study clinical practices, it seems equally well suited to educational practices, including those involving technology'.

Praxiography employs ethnographic methods to understand 'not only the human dimensions of socio-material relations, but also the materiality of those relations in the constitution of practice' (vu Henry, 2018: 69 - 70). For example, Suchman (1985) recognised the 'value of ethnographically based attention to practice' during her research at PARC, a research and development company based in California. There are some useful methodological accounts of praxiographical-inspired ANT research, mostly in the literature related to educational technology (Sørensen, 2009; Thompson and Rimpiläinen, 2012), but scarcely any which discuss interdisciplinarity. Callard, Fitzgerald and Woods (2015: 4), who, like me, set out to explore interdisciplinarity 'in action', explain that:

> "…there remains no sub-field of ethnographic collaboration studies, and no sustained attention to the micro-practices of interdisciplinary working, despite the prominence of this norm within the contemporary academy. The relative paucity of this literature is striking vis-à-vis the usual attention to 'science in the making'

within the science and technology studies (STS) literature… much STS has taken place within the genre of 'laboratory ethnography'"

3.2.2 Collective case study

A historical tradition of ANT is committed to its development through case studies. 'The case study aims to understand the case in depth, and in its natural setting, recognising its complexity and its context' (Punch, 2013: 120), and I have acknowledged multiple times the complexity inherent in studying interdisciplinary research and the co-production of new technologies *in situ*. 'Co-production begs for illustration rather than proof' (Jasanoff, 2004: 6), and it is important to gather 'context-rich accounts of the…social realities of technology use on the ground in educational settings' (Selwyn, 2010: 66). 'Like interdisciplinary outcomes, technology…needs to be seen as developing from use… emergent use[s] are important aspects of interdisciplinary, collaborative practice' (Haythornthwaite et al., 2006: 161). Yin (1989) also argues that a case study is the most adequate strategy to tackle problems which ask 'How?', and this fits well with the research question.

It must also be briefly noted that my literature review found no single paradigmatic methodology when conducting research in the area of interdisciplinarity and technology. Conole et al. (2010) employed qualitative methods though fora and interviews; Hidayanto and Setyandy (2014) and Qin, Lancaster and Allen (1997) opted for quantitative research; Berry (2012) used ethnography; Rafols and Meyer (2010) reviewed bibliometric studies such as that by van Raan and van Leeuwen (2002); Hermann, Rummel and Spada (1998) took an experimental approach; Clough, Conole and Scanlon (2010) took a participatory approach; and Rhoten (2004) and Haythornthwaite (2006) used social network analyses. The 'Inventing Indicators of Interdisciplinarity' (2018 -), a collaboration between the Centre for Interdisciplinary Methodologies at the University of Warwick, and the Centre for Science and Technology Studies at University of Leiden, aims to use 'scientometrics' and visualisation in order to devise alternative approaches to evaluating

interdisciplinarity. I specifically decided not to take a quantitative approach like Wuchty, Jones and Uzzi's (2007), since bibliometrics aim to 'measure' interdisciplinarity (for example, through citation analysis), and as such 'bibliometric studies [give no] indication of the underlying processes' (Shrum, Genuth and Chompalov, 2007: 8), a key point in which I have established I'm interested. But 'case studies… overcome the main limits on bibliometric research' in the area of interdisciplinary collaboration (Shrum, Genuth and Chompalov, 2007: 8). Moreover, as introduced during the literature review, I have found Barry, Born and Weskalnys' (2008) programme of study of interdisciplinarity, responding to the 'paucity of empirical studies of how interdisciplinarity unfolds in practice,' methodologically very valuable (Barry and Born, 2013: 2). Barry and Born (2013: 2) undertook 'ten case studies of interdisciplinary institutions and initiatives and the practices they supported', and I have drawn from this in the selection of a case study approach.

A collective case study is conducted at one site, for example, a University, by examining several different departments or other units at that one site (Flyvbjerg, 2006; Goddard, 2010). Goddard (2010: 751) explains that 'collective case studies examine at least three cases in any given study… to understand the phenomenon deeply from a variety of perspectives'. I chose a collective case study in order to access a broader spectrum of disciplines – including different 'mixtures', constitutions and applications of these disciplines - than would have be possible with one case alone. I wanted to access a broad range of different disciplines across the projects to investigate how interdisciplinarity might be enacted differently, or similarly, when different disciplinary fields and actors are involved. The use of multiple cases is motivated in-part by the logic of comparison in an embedded case design (Yin, 1994: 57). It must also be noted here that although the choice of the University at which to conduct fieldwork was important, the choice of the cases themselves was even more important due to the their fundamental position as the sites for data collection (see section 3.3.2).

The 'traditional' (collective) case study approach must be attended to momentarily here, since it inherently suggests 'pre-conceived boundaries' that seem contrary to ANT's sensibilities. This potential quandary is somewhat similar to post-modernist discussions in digital ethnography around 'assembling a combination of ethnographic and case study approaches' (White, Drew and Hay, 2009: 22). As such, I conceive of the three selected research projects, cases, as 'different instances of the network'; that is, individual actor-networks situated within the broader institutional network of the University. This will open up space for potential further discussion and comparison of the projects as part of the broader University interdisciplinary 'ecosystem'. This is in line with my ANT framing, as well as the methodological implementation of the collective case study approach, and further rationale for undertaking a collective case study, along with the design of and methods used within each case, will be discussed in sections 3.3.3 and 3.4.

3.3 Researching research projects in Higher Education

This section presents the practicalities involved in researching research projects, including navigating access to those suitable for empirical investigation, as well as conducting ethnographic research within institutions and projects outside of my 'home' institution and disciplinary areas.

3.3.1 Navigating the field: choosing case study sites

Criterion: Technology 'in-the-making'

Cases were selected with care in relation to the conceptual and theoretical framework of the study, and as such my methodology includes purposeful selection of case study sites. Close to the beginning of my D.Phil research, from January 2016, I carried out desk research to search for potential cases, based upon the approaches tested within my pilot study (Appendix B).[43] I had to be very open and adaptable to what I might find, but

[43] My qualitative, interview-based MSc dissertation research, in which I explored interdisciplinary practices across four small cases based at the University of Oxford, acted as a form of pilot study. It

generally, I sought early-mid stage interdisciplinary research projects based at Universities, in which an innovative technology was being developed – or at least there was the intention to build technology.[44] I was interested to open up 'grand narratives' of innovative technology which often go hand-in-hand with 'grand narratives' of interdisciplinarity, as well as focus on exploring emerging technologies, typically characterised by technological and societal uncertainties and expectations. According to Latour's 'first rule of method', ANT approaches science and technology 'in-the-making' (Latour, 1987), and Layton (1977: 209) argues that '…what is needed is an understanding of technology from inside, both as a body of knowledge and as a social system'. As Latour (1987: 258) argues, 'we study science in action… to do so, we [can] arrive before the facts and the machines are blackboxed'.

Criterion: 'Interdisciplinary' by name

As established in Chapter 2 (Literature Review), 'in most universities, research is organised along the same departmental lines as the undergraduate degree courses, and therefore follows the same disciplinary boundaries' (Blackwell et al., 2009: 27). Thus, I honed in on Higher Education institutions with strong histories and cultures of interdisciplinary innovation. It was of crucial importance that potential cases seemed to offer a 'depth' of data suitable for collection during an ANT-inspired praxiography, and this meant that all selected for further investigation were 'interdisciplinary' endeavours approved and funded by significant granting agencies, and supported to some extent by University infrastructures.

Initial visits across three potential University sites

Once I had identified a number of research projects which could act as potential cases across three Universities in the USA, I carried out initial desk research (such as looking at

was a helpful exercise in negotiating access to typically 'closed' research sites, as a disciplinary 'outsider', as well as testing interview approaches, for example.

[44] Miles and Huberman's (1994: 28) criterion sampling.

websites and publicly available project-related documents), and visited as many as I could on-site, September - October 2016. As I described earlier in this thesis, the USA has cultivated strategies, policies and structures around interdisciplinarity (Sá, 2007). As such, this burgeoning interdisciplinary ecosystem, alongside high levels of investment into new technological development, motivated the choice to conduct fieldwork at a University in the USA. My entry point was to conduct sixteen preliminary, semi-structured, audio-recorded, expert-researcher interviews with 'interdisciplinary practitioners' within the potential cases across the US Universities. Interviews lasted between 30 minutes – 1 hour each, at times and locations amenable to the participants' schedules. The interview schedules explored interviewees' reflections on their own research practices, the specific research projects in which I was interested, and their thoughts regarding interdisciplinarity, among other areas. These visits also led to one Focus Group, two observations, and two further methodologically-focussed expert-interviews (so, eighteen 'interviews' in total) (Appendix C). These interviews were held with researchers spanning musicians, to computer scientists, to biologists, to artists, to mathematicians.

This preliminary data collection allowed me to scope for the most appropriate cases for inclusion in my research. In addition, the interviews were elucidating to inform both the direction of my continued literature review, as well as my emerging methodological framework. Participants were generally extremely interested in my research topic; they also helped to confirm the viability of exploratory themes around interdisciplinarity which I had extracted from the literature, and gave me the opportunity to test the feasibility of my methodological approach. Gaining access to these projects was initially a challenge, through a series of cold emails and relationship-building, but face-to-face meetings made it easier to forge strong foundations with research communities, and thereby to gain access to the projects.

It was through this 'preliminary' research at one of the Universities I visited, University X, that I crucially gained access to an interdisciplinary research catalyst within which I found

my 'home-base' during the most significant phase of data collection in this study. During the week-long initial visit to University X, I formed a strong relationship with the Executive Director of this catalyst, which I call Hub. She was my 'gatekeeper' to University X, and she invited me to carry out my research as an official Visiting Student Researcher. This preliminary stage of my research was also absolutely crucial in forging the relationships with participants in the individual research project cases at University X.[45]

3.3.2 Gaining 'insider-outsider' access to University X

University X, the University within which I chose for my empirical data collection to take place, is a University in the USA with a strong socio-historical culture of interdisciplinarity and technological innovation. This institutional culture, combined with the suitability for empirical investigation of the research projects which it housed, as well as the position of Hub within its infrastructure,[46] motivated my selection of this site for the study (alongside analysis of the initial pilot work to support my choice). The Hub is part of a larger institute at University X which is branded as an 'interdisciplinary research centre focusing on people and technology' that 'pursues its mission in a number of ways, all built on [the] core belief in the power of collaboration'. They organise interdisciplinary grants, contracts, and other funding opportunities, among other activities, bringing together faculty from across the University to work collaboratively on projects. The Hub website describes themselves as an 'affiliate programme… extending from the Graduate School of Education to over two dozen interdisciplinary labs at [University X]'. In addition to their goal to connect researchers from different disciplines, they also bring '…innovative companies and researchers together to explore thoughtful uses of information technology across the industries of tomorrow'[47]. This study explores three interdisciplinary research projects

[45] See section 3.3.3 for description around why and how I chose the three cases from the potentials identified.
[46] See further motivation below for my choice of Hub within University X as my 'homebase' during investigations.
[47] This gave me additional insight into the Energy case (CS3) due to the industry stakeholders which I found to participate in enactments of interdisciplinarity (see Chapter 6).

based at University X, and thus this University forms an important and pervasive 'context'.

In addition to my initial trip, I undertook a follow-up visit to University X in March 2017 in order to establish and finalise my practical research plans with gatekeepers from each of the three research projects I had selected. The most significant phase of my empirical research began in May 2017 when I moved to the USA as a Visiting Researcher at the University. I spent a year in the field at the Graduate School of Education at University X (see Appendix D for my invitation and endorsement letters from University X). I was also in remote communication with my contacts at Hub, as well as my participants across the three chosen cases, for seven months altogether either side of my time in the field. The duration of my 'face-to-face' data collection was determined not only by the length of my visa, and thus the length of my term as a Visiting Researcher, but a year is also a suggested optimal minimum length for ethnographic fieldwork (Hammersley, 2007). In most ANT studies of scientists and technologists, the ethnographer is found in the field or the laboratory for long periods of time (Sismondo, 2010).

I lived nearby to University X and commuted daily to my office, located in the Hub (see figure 1). During my time at the Hub, I collaborated with the small team of 5 researchers to write a conference paper, exploring the Hub as a case study of 'multidisciplinary collaborative network development'. Additionally, I was invited to present some of my emerging findings at a number of interdisciplinary conferences and workshops organised by the Hub, including a seminar which I led called 'Interdisciplinary Collaborations'. These activities helped to sensitise me to, and become intimately acquainted with *and part of*, the broader 'interdisciplinary ecosystem' and infrastructure of University X. Morrison (1993: 88) argues that by 'being immersed in a particular context over time not only will the salient features of the situation emerge and present themselves but a more holistic view will be gathered of the interrelationships of factors'. My case participants were invited whenever I spoke at Hub events, to learn about my research methodology

and emerging findings, a deliberate choice for participant transparency (Given, 2008). It is also interesting to note that the PIs of each of the cases were involved to differing degrees with the Hub, whether they spoke often at Hub conferences (the PI of Medical Robotics, CS1), or attended Hub events (the PIs of Digital Humanities and Energy, CS2 and CS3).



Figure 1. My shared office in the Hub, at University X (Photo by Erin Young)

It must be noted that my status as a Visiting Researcher afforded me an increased level of trust with the case study participant-researchers, and Meyer (2001: 336) explains that 'the issue of building trust between the researcher and the interviewees [is] very important'. This was of particular importance in order that they would feel comfortable enough to share project documents with me, for instance. With my University card, I had access to the entire campus, including University libraries, and 'private' spaces where case study project meetings were held. I was also issued with an email address for University X, through which I corresponded with participants, as well as with the Learning Technologies research group at the Graduate School of Education of which I was a part. Following my year in the field I maintained correspondence with many of my participants,

including those with whom I had worked at the Hub, in order to verify particulars and collect further data where relevant.

3.3.3 The chosen cases

Two important methodological points about the cases studied in this thesis must be made. Firstly, since ANT is fluid and suspends a priori labels, approaching interdisciplinary research projects contextually as 'cases' was purely a practical 'starting-point'. 'The research field should be made wide open to begin with…' argues Latour (2005: 85), and thus there were no fixed boundaries to the cases throughout data collection and analysis. I 'cut the network' of the cases as I undertook data collection and analysis (Strathern, 1996), and I understand this in a similar way to traditionally establishing 'boundaries' of cases (Stake, 2008; Elger, 2010). I did so *during* fieldwork, allowing me to define a scope of exploration and analysis that could accommodate the heterogeneity and potential mobility of interdisciplinarity.

Secondly, as previously described, I chose to conduct a collective case study, whereas many 'traditional' ANT studies typically focus only on one case. In order to establish comparative logic and answer the research question effectively, it was crucial to gain access to a diverse range of researchers situated broadly across the disciplinary spectrum. This allows me to understand interdisciplinary enactments more broadly, and to explore knowledge and technological co-creation across a range of disciplinary and interdisciplinary ontologies. I therefore chose cases which covered a variety of specialisms within the applied sciences, medical sciences, social sciences and humanities. This is a purposefully selected sample to embody a range of experiences related to my phenomena of interest (Patton, 1990). The cases represent a wide array of different iterations of (interdisciplinary) researchers working together, and there are a multiplicity of heterogeneous participants engaged throughout, since '…for collective case studies, selection by…balance and variety are important; opportunity to learn is of primary importance' (Stake, 1994: 244).

Thus, this study is a praxiography of the 'laboratory life' of three technologically-mediated interdisciplinary research projects, based at University X (Latour and Woolgar, 1986). As previously mentioned, I found it easiest to 'draw close to' the chosen cases via one or two researchers, the gatekeepers, on each project. They were the main source of information at the beginning of fieldwork, and they were helpful for further determining whether my methods, chosen through adherence to the research question and methodological underpinning, could work in practice in their empirical settings (Hammersley, 2007).

The projects were funded by different bodies, were comprised of different 'disciplinary' compositions, and had different project goals. All three laid a claim to being 'interdisciplinary', whether this was in the grant proposal, or 'vocally' during research. Human researchers across the projects include Principal Investigators (PIs), Professors, Undergraduate students, Postgraduate students and Postdocs, and a wide variety of non-human actors participate within all three. Teams are generally co-located in University X, with some geographical distribution due to external project collaborations, to varying degrees. Due to the uniqueness of each of the cases, I adapted and relied upon different research methods for different cases at different times. The task was to follow the unfolding practices of the following three teams moving from research questions to emerging technological outcomes, in order to investigate their technologically-mediated interdisciplinarities 'in-the-making'.

Case 1: Medical Robotics (CS1)

This research project, Medical Robotics, is working to develop a robotics platform for administering liver surgery. The team ultimately aim to work towards clinical adoption, building a robotics system which integrates a steerable needle in order to improve access and accuracy in radio-frequency ablation (RFA) procedures targeting tumours in the human liver. They are also developing an imaging system for needle location to work alongside this, which would allow surgical ablations to be performed without requiring multiple punctures of the liver, as is the current surgical practice with traditional needles.

The project is funded by a large governmental agency in the USA, responsible for public health research. I joined the project over mid-way through their funding cycle, and when I left there was uncertainty as to whether further funding would be sought. The 'core team' consists of a small number of engineers and clinicians,[48] working on the design and development of the needle, and its integration into a prototype robotic, surgical device. The project is based within a Robotics lab at University X, and the analytic token followed here is a steerable needle.

This project, like the other two cases, was specifically chosen both for practical and conceptual reasons. The growing interest in medical practices in the field of ANT suggested that it would be an interesting case to investigate (Mol, 2002), and the initial, exploratory conversations I held with the project PI produced interesting initial ideas around the conceptualisation of interdisciplinarity in a project involving engineers and medical doctors. I explained my research, and what it might entail, to the PI during my initial visits to University X, as well as through a Skype call before I entered the field. Following this, I was granted a significant degree of access to the project.

Case 2: Digital Humanities (CS2)

In this 'Digital Humanities' project, the research team work to design a prototype digital tool for organising humanities data, building on an existing suite of data visualisation and cartographic tools which some members of the project team had previously developed within a wider branch of the project. The software, which connects linked data sources to filtering and graphing tools, aims to provide a framework for historians and other humanities researchers to access and explore historical data. The broader high-profile research project, within which this initiative is located, received funding in three phases, and I joined the project at the beginning of the final phase. The project was funded by a private, non-profit representing American scholarship in the humanities and social

[48] See Findings chapters for *nuanced* investigations of the 'interdisciplinary teams' in practice.

sciences, as a 'digital extension' to the wider initiative. This lasted for one year, and I was engaged throughout.

The project is situated within a research centre at University X, based at the School of Humanities and Sciences, exploring '…digital tools and methods to create new knowledge in interdisciplinary humanistic inquiry'. Initial contact with the project included a tour of this research centre during my first visit to University X. Conversations with the project team during this tour suggested that this would be an interesting environment within which to investigate interdisciplinarity, due to a conscious dialogue around, and considered promotion of, the phenomenon (that is, an interdisciplinary 'self-awareness'). Neither of the other projects chosen seemed to have an ongoing discourse around their 'own' interdisciplinarity in this way, and as such the researchers on this case seemed the most excited for me to join as a 'co-researcher' into the nature of their interdisciplinarity. Additionally, this case enables the potential for an exploration of a nascent interdisciplinary field, the Digital Humanities (Berry, 2011). There are seven researchers listed as the 'core team' on the official project website, the majority of whom will be human actors to whom I attend in the forthcoming Findings chapter (Chapter 5), and they represent 'disciplinary inputs' including historians and software engineers. This case is the most geographically-distributed of the three research projects, and the analytic token to follow here is the concept of 'encoding a humanities epistemology' into a technology.

Case 3: Energy (CS3)

The goal of this well-funded initiative is to develop integrated hardware and software to aggregate and control energy resources, constructing a more sustainable and reliable Energy grid. The project was conceived as a response to modern day Energy challenges, and the research investigates how to design and build computer systems to manage Energy and minimise its consumption. The team aim to build a system that will enable real-time coordination of utilities' assets with distributed resources through the integration of embedded sensing and computing, power electronics, data analytics and

networking with cloud computing. The project is predominantly funded by a United States government agency which funds research into advanced energy technologies, and it partners with a number of external stakeholders, including high-profile technology companies.

I met with the gatekeeper of this project, a sociologist and project manager, during my initial visit to University X. Following this conversation, during which an outline of the project was presented to me, it seemed an interesting case choice primarily due to the differing nature of its 'surface' interdisciplinarity in comparison with the other two cases. By this, I mean that the disciplinary make-up of the team – a measurement through which interdisciplinarity is 'traditionally' deemed to be quantifiable – was not as diverse, since most project researchers came from an Engineering background. Furthermore, this is the only case I have chosen which includes direct industry and government collaboration, as well as a collaboration with another University, and this seemed to be an interesting project dimension with respect to consideration of its interdisciplinarity. I joined the project shortly after funding was granted. The analytic 'token' followed here is a postgraduate researcher, Marco.

3.4 Design and methods of data collection

Like the research question, the research design was not absolutely fixed as I entered the field, and it developed as my fieldwork progressed. 'Design has to be an ongoing concern, a constant weaving back and forth between a conceptual framing and the intellectual problem at issue' explain Mills and Morton (2013: 43). My methodological research design supported exploration of interdisciplinary enactments, and more specifically, socio-material practices and materialities of interdisciplinarity in research projects co-developing new technologies. Research design 'situates the researcher in the empirical world, and connects the research questions to data' (Punch and Oancea, 2014: 142; Denzin and Lincoln, 1994). As such, I have laid out my argument thus far in this chapter to show how my overall strategy and framework is driven by the research question, and in

turn, drives the project design. Furthermore, to honour the complexities inherent in studying technologically-mediated interdisciplinary research practices, and to acknowledge multiple human and non-human actors' 'voices' within a multiplicity of relations, I engaged multiple methods based upon interdisciplinarity as the object of study, like Callard, Fitzgerald and Woods (2015), Rimpiläinen (2012), and Barry, Born and Weszkalnys (2008). ANT acknowledges the use of multiple data sources as a way to a strengthen a case (Elsayad, 2016: 98), and STS ethnographies often involve the collection of multiple forms of data sourced from various points of contact within the field (Wilkie, 2010). Furthermore, Gillham (2000: 2) sees the use of multiple sources of evidence as a 'key characteristic of case study research'. I chose a combination of methods which could permit me 'access' to all the potential actors who might be brought to the foreground in each project network; and crucially, access to their emergent realities in-the-making (Mol, 2010).

As previously established, 'ANT studies represent an enormous array of empirical and analytic methods' (Fenwick and Edwards, 2010: 145), offering 'no consistent method' (Mol, 2010: 261). 'ANT may offer a vast range of promising methods to engage with empirical data, but it does not furnish easy guidance on which of those methods to adopt', explains vu Henry (2018: 80). Thus, in looking to 'reconcile' ANT with 'traditional' qualitative methods, Wright (2016) extended me some guidance, along with Fenwick and Edwards (2010: 151) who explain:

> "Educational researchers working with ANT gather information in various ways. Most utilise some form of field observation following well-known ethnographic approaches: immersion in the site, focused observation of particular events or time periods, systematic note taking in real-time,... collection of documents and artefacts, and site conversations with participants, perhaps audio-recorded and transcribed... More rarely, others such as Mulcahy (2006) have worked entirely

from interviews, analysing the diverse networks that can be inferred in the discourses and narratives expressed by people."

Table 1 below illustrates some of the research design 'figures' for each of the three cases, with respect to the methods chosen. These show the number of observations and interviews undertaken, project documents collected, and photographs taken. Case data were collected simultaneously, according to the schedules of each of the three research projects. Motivations for each will be explored in-depth in the following sub-sections.

	Medical Robotics	**Digital Humanities**	**Energy**	Total
Observations	9	14	31	54
Interviews	11	7	17	35
Project documents	36	151	95	282
Photographs	77	11	7	95

Table 1. Research design for individual cases

3.4.1 Observations

Observation is a central tenet of ethnography (Spradley, 1980), and therefore praxiography, and observations formed a significant part of my data collection across all three cases. Jasanoff (2016) recognises that observation proves a useful tool for exploring the 'cultural dynamics of different scientific disciplines'. According to Flick's (1998: 137) dimensions, my observations were unstructured and overt, allowing me to 'follow the actors', as previously described, tracing the development of technology *in situ* (Punch and Oancea, 2014). Socio-Technical Interaction Networks (STIN) heuristics, that is, 'a tool for understanding socio-technical systems in a way that privilege[s] neither the social nor the technical' (Meyer, 2006: 37), also offered a 'way-in' to identify potential analytical tokens to follow during observations, and I was sensitive to all actors, both human and non-human, and their relationships. Adapting a list of eight illustrative 'steps' developed in the

STIN tradition (derived from ANT) by Kling, McKim and King (2003: 57) helped me to further sensitise to ANT *methodologically*, to associate it with 'traditional' qualitative methods, and thus to draw closer to empirical evidence. [49] I also used LeCompte and Preissle's (1993: 199) guidelines to help direct observations: How many people are there in the group, and what are their identities and characteristics? What is taking place? What resources (for example, technologies) are being used in the scene? How do different participants behave towards each other? What is being discussed frequently? I found Spradley (1980) useful as well for dimensions of descriptive observation: actors; activities; objects; acts; time; goals; and so on. I was not granted permission to film any observations, so my field notes were thorough, including on-the-spot transcription should I have felt it necessary (DeWalt and DeWalt, 2002). Indeed, Latour (2005: 133–135) suggests keeping a series of notebooks during fieldwork to log inquiries and thoughts, and keep track of events chronologically. Whilst I did not use four separate notebooks as he proposes, I did keep detailed field notes, particularly during observations, and these were crucial during the methods crystallisation and data analysis stages. Given the twinned ambitions of evoking experience and creating analytical meaning within an ethnographic approach, I constantly reflected upon my notes, and since they 'play an invaluable role… they are worth keeping as fully, and as carefully, as possible' (Mills and Morton, 2013: 91). According to Gold's (1958) observational classification continuum, and consistent with the conceptual framing of ANT, I situated myself as the 'observer as participant'. 'The observing participant needs to maintain a delicate balance between participating and observing', explains Sørensen (2009: 21).

[49] For example, with my adaptations and annotations in parentheses, step 1: 'Identify a relevant population of system interactors' (the case study); step 2: 'Identify core interactor groups' (interdisciplinary collaborations and key actors); step 6: 'Identify resource flows' (ideas, concepts, for example); and step 8: 'Describe configurations and outputs' (during the four moments of translation). This 'checklist' of heuristics is also reminiscent of the questions asked of 'hybrid assemblages' by Thompson and Rimpiläinen (2012: 7), including: how are they brought together? What disruptions or stabilisations led to the configuration?

My observations took place mainly within physical spaces since, when possible, I went to the research sites and followed in real-time the unfolding (interdisciplinary) processes of each team moving though their research. For the Medical Robotics project (CS1), observations took place primarily in two different labs: an engineering/robotics lab, and the 'Zeevo' lab based at the hospital of University X. I carried out observations at the Zeevo lab during a number of experiments run by the team to test their prototype technology. For Digital Humanities (CS2), my observations primarily took place during three design workshops which the team held throughout the duration of the project. For 'Energynet' (CS3), I attended many of the (typically, hour long) weekly team meetings held at the Environment and Energy Building on campus; I was also invited to attend multiple smaller project discussions between the researchers. I observed four quarterly 'site visits' between the project team and the funding body, held on campus or at the nearby government-owned national accelerator laboratory (a partner on the project). The most significant of these 'site visits' was a Lab Launch which took place at University X. Virtual observations also took place, in a lesser capacity, across the cases; this included, for example, via the project Slack for Digital Humanities (CS2); through the mailing list, as well as a number of Zoom video conference calls, for Energy (CS3); and via Skype meetings for Medical Robotics (CS1).

3.4.2 In-depth (expert-researcher) interviews

Whilst I was careful not to focus exclusively on human actors, interviews with researchers across the projects helped me to become attuned to the multiplicity of, sometimes contradictory and conflicting, diverse disciplinary realities within each case. Indeed, digging into researcher 'biographies' and viewpoints helped suggest the 'entanglement[s] of networks where their research approaches and practices stem from, how they understand the research question [on their project] and what their aims are for engaging with the [other] discipline[s]' (Rimpiläinen, 2015: 77). I conducted thematically-guided, semi-structured, in-depth interviews with the 'expert-researcher' participants regarding

their views on and definitions of interdisciplinarity; reflections on their research project (including project methodologies); technologies being built; among a number of other areas, some of which came to the foreground during the interviews. These topics offered insight into the ways in which the researchers approached their projects, how their researcher (disciplinary) 'hinterlands' were enacted in practice (as termed by Rimpiläinen, 2015: 137; Law, 2004), and what types of materials, people, data and information gathered as a result (Rimpiläinen, 2012: 64). In accordance with my methodological framing, I carried out interviews with researchers as the analytical tokens which I was following seemed to come into contact with them. Interviews can prove particularly effective because they can illuminate practices with 'rich description' (Strathern, 2005: 85), when 'not many projects reveal insights into collaboration experiences' (Jänicke et al., 2015).

I drew from the *Interdisciplinary Collaboration Exploration Project* to inform the use of interviews. Mulcahy (2013: 7) explains that, following a survey of researchers across funded interdisciplinary research groups at a University, semi-structured interviews with individual researchers were carried out '…to achieve an understanding of what was important to the researchers while engaged in interdisciplinary research'. I also chose to run semi-structured, in-depth interviews since the establishment of 'unifying' topics to discuss in all interviews provided a sense of cohesion during data collection, but with a flexibility which allowed for the emergence of new themes (Kvale, 1996). In accordance with Bergman and Coxon's (2005: 20) suggestions, I held a number of unrecorded, exploratory interviews with the project gatekeepers during my initial and follow-up visits to University X in order to, at the very least, give me an informed understanding of where I could begin my investigations with ANT. "Latour (1999: 20) has emphasised that in talking with human participants, the focus is upon understanding what things and people do, not what they mean: 'actors know what they do and we have to learn from them not only what they do, but how and why they do it'. The point is to trace complexity and

heterogeneity" (Fenwick and Edwards, 2010: 151). Additionally, I found advice from Mitchell (2017) valuable when employing interviews within an ANT-guided study:

> "The 'human' who think you are interviewing is actually part of a human and non-human network that they cannot extract themselves from… interviewing is to create a space for the participant to speak, and for this to be a way to hear accounts about interactions and associations that [one cannot] directly witness."

Upon leaving the field, I had carried out 35 interviews in total: 17 formal, audio-recorded interviews with researchers on the Energy project (CS3), 7 for Digital Humanities (CS2), and 11 for Medical Robotics (CS1) (see Appendices E and F for full list of interviewees and for a sample interview schedule). Interviews across the cases lasted between 45 minutes – 1.5 hours, at the location (and time) of the participants' choice on campus, negotiated via email and in person. I interviewed most of the participants once, with some follow-up interviews if necessary. In addition to this I held a large number of informal and unrecorded conversations with project researchers during my time in the field. It has been important to distinguish between interviews and other data sources in the findings chapters, in particular to differentiate between enactments of interdisciplinarity, and participants' opinions towards and experiences of interdisciplinarity.

3.4.3 Documentary gathering, review and analysis

I was granted access to some proprietary (secondary) data across the cases (Bowen, 2009; Silverman, 2011). When I first began data collection, and before I physically entered the field, I had gathered a significant number of publicly-available project documents via desk research. This online research contributed to my initial overviews of each project, shedding light on potential actors, practices, methodologies and technologies of interest before my empirical research took place, helping me to begin to identify the 'actors to follow'. During my fieldwork, I took the 'jackdaw mentality' as described by Robson (2011: 351), ensuring I was always on the lookout for documents and other objects of interest. Documents collected from the Medical Robotics (CS1) case include journal articles and

conference papers, as well as websites. Digital Humanities (CS2) documents include Slack transcripts, over 100 uploads to Slack (including images, demos, graphs, notes, and other documents), hand-drawn diagrams, wireframes and websites. Documents from the Energy project (CS3) include transcripts of email correspondence, PowerPoint presentations from the quarterly site visits, academic articles and papers, websites, google docs, project brochures, the grant proposal, and weekly meeting minutes. Documentary analysis is particularly important for ethnographers, providing a 'rich vein for analysis' (Punch and Oancea, 2014), and Latour (1987) stresses the importance of examining inscriptions – that is, writings and artefacts created by the actor-network; this includes my own observation field notes.

3.4.4 Technical artefact identification and photography

Sørensen (2009: 3) explains that '…doing an ethnography of new… technologies means studying them in practice', and Gillham (2000: 89) emphasises the utility of physical artefacts since 'physical evidence has a direct quality: it is first hand.' Upon entering the field, I had initially only intended to identify and photograph technologies-in-development across the cases, as per my research question. However, once I was immersed in the projects, I realised the value of also photographing the environments within which these were constructed, and the tools with which they were being constructed, as well as the researchers interacting with and building these technologies. I drew from Adams and Thompson (2011: 734) who formulated heuristics to 'interview artefacts' in order to 'catch insightful glimpses of the artefact in action'. I wanted to engage *deliberately* with non-human actors, and in particular, technological objects, responding to Latour's (2005: 79) call to 'make [objects] talk, that is, to offer descriptions of themselves, to produce scripts of what they are making others, humans and non-humans, do'.[50] In accordance with ANT's 'generalised symmetry', I traced in real-time the

[50] Adams and Thompson's (2011) first cluster of heuristics involves 'attending to objects, attuning to things' to identify possible entry-points into an exploration of a heterogeneous actor-network.

emergence of technologies within each case, as inspired by Thompson and Rimpiläinen (2012) and Adams and Thompson (2014). 'Recognising technologies-in-use as agential in co-shaping the existential and hermeneutic conditions of our lifeworld suggests educational researchers may be obliged to consider such technologies as relevant research participants' (Adams and Thompson, 2011: 733). I photographed technological assemblages according to the technologies-in-development as follows: the Medical Robotics project (CS1) was building a new robotics platform; Digital Humanities (CS2) was designing new software; and the Energy research project (CS3) was building components for a new Power Grid (including a Cloud device, a dimming fuse, and a central home hub). I also employed the talk-aloud protocol at times (Ericsson and Simon, 1993), particularly for CS1 and CS2, watching and asking questions as researchers interacted with the technologies-in-development.

3.5 Methods of data analysis

The intent of ANT analysis is typically to describe how networks come together, and stabilise or fall apart. Thus, according to the framing of my research question, my analysis centred upon how the socio-material networks of practices of technologically-mediated interdisciplinarity in research projects came together, or not, and achieved stabilisation, or not. In order to help me attune to enactments of interdisciplinarity 'as they happen', I moved between the different data sources collected, in a 'scale-free' way, attempting to identify 'critical' or significant moments, or when a decision was taken regarding the direction of the research process. I drew from Rimpiläinen's (2012: 54) approach to analysis (through 'translation'), when she explains that 'being a participant in the midst of unfolding processes, I have ended up scanning the events back and forth in time and space. It is through reflection and the blessing of hindsight that I have been able to pick out some events as relevant for the translations of the token, even if at the time this event

The second type of heuristic allows the researcher to 'loosen the network' and further analyse the materialities of the gathering. These heuristics are presented as part of a set of possible analytic strategies from which to choose.

took place it did not seem important'. Rimpiläinen (2012: 66 - 67) continues, explaining that:

> 'Given the unfolding and indefinite nature of the research topic, initially everything potentially became data! In order to manage the huge data set I created a word-table detailing all research events (meetings, interviews, observations, negotiations etc)... This enabled locating any event chronologically with the associated data... Until 'the something' finally emerged from the research and development process it was not possible to say which bits of data were relevant and which bits could be left out'.

Interview analysis

Themes derived from analysis of the interview transcripts across the three cases were particularly helpful in guiding my overall analysis. Having been audio-recorded on a secure device and transcribed, I pre-coded all the interviews (Layder, 1998), keeping a copy of the (evolving) research question(s) in front of me in order to maintain focus when marking my transcripts (Auerbach and Silverstein, 2003: 14). I began pre-coding under the guidance of Richards (2005), who encouraged me to 'develop a memo-writing routine that encourages quick and easy documentation of the ideas and the ways ideas grow'. As my coding progressed, I referred to Saldaña (2013). Aligning my methods of coding with my research question, I used eclectic coding which, through multiple iterations, transformed into a combination of topic, descriptive and process coding (Bogdan and Biklen, 2007; Saldaña, 2013: 111). The 35 audio-recorded interview transcripts were uploaded into NVivo together with any other data that could be uploaded, such as documents and photographs. I organised and tagged them for codes and categories, as well as relevant connections and happenings, making them easy to locate during my research process. I drew from Wright (2016: 30) to explore how 'ideas from actor-network theory can be drawn on to inform ways of using computer assisted qualitative data analyses in an ANT-oriented project' in what he terms a 'CAQDAS-ANT assemblage'.

Individual case analysis, to collective case analysis

I became familiar with each case as an individual entity, heeding Crowe et al.'s (2011: 7) advice that 'in collective case studies, it is helpful to analyse data relating to the individual component cases first, before making comparisons across cases'. Within each case, I crystallised the multiple methods through analyses, paying particular attention to my core research question. My choice of crystallisation within a collective case study also adds quality assurance to my research because '…multi-case sampling adds confidence to findings [since] by looking at a range of similar and contrasting cases, we can [better] understand a single-case finding' (Miles and Huberman, 1994: 29). The research question helped to focus my analysis on the potential for stabilisation or de-stabilisation of networks, re-negotiations of methodologies, and other potential instantiations of socio-material interdisciplinary practices, and I simultaneously analysed observational, documentary, interview and technical artefact data.

Observational data was analysed following the principles of Strauss and Corbin (1990) and Cohen, Manion and Morrison (2013: 469), so categories were derived empirically from the data rather than assigned based on existing taxonomies. I ran content analysis on documents of significance, since Bryman (2004: 542) states that qualitative content analysis is 'probably the most prevalent approach to the qualitative analysis of documents'. Content analysis, with technologically-mediated interdisciplinarity as the object of research, was used as 'a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use' (Krippendorff, 2004: 18). This was validated against individual, chronological hand-drawn project timelines which I drafted during data collection (see figure 2), since empirical data collection and analysis ought to be 'developed together in an iterative process' (Hartley, 2004: 329). Comparison between the cases was the next stage of the process, and 'the idea behind cross-case [comparison]… is to force investigators to go beyond initial impressions' (Meyer, 2001: 342). I took a similar approach to data analysis

in a collective case study as Meyer (2001: 341) who 'went through the stages by which the data were reduced and analysed… establishing coding, writing up the data according to themes… [and] comparing the cases'.

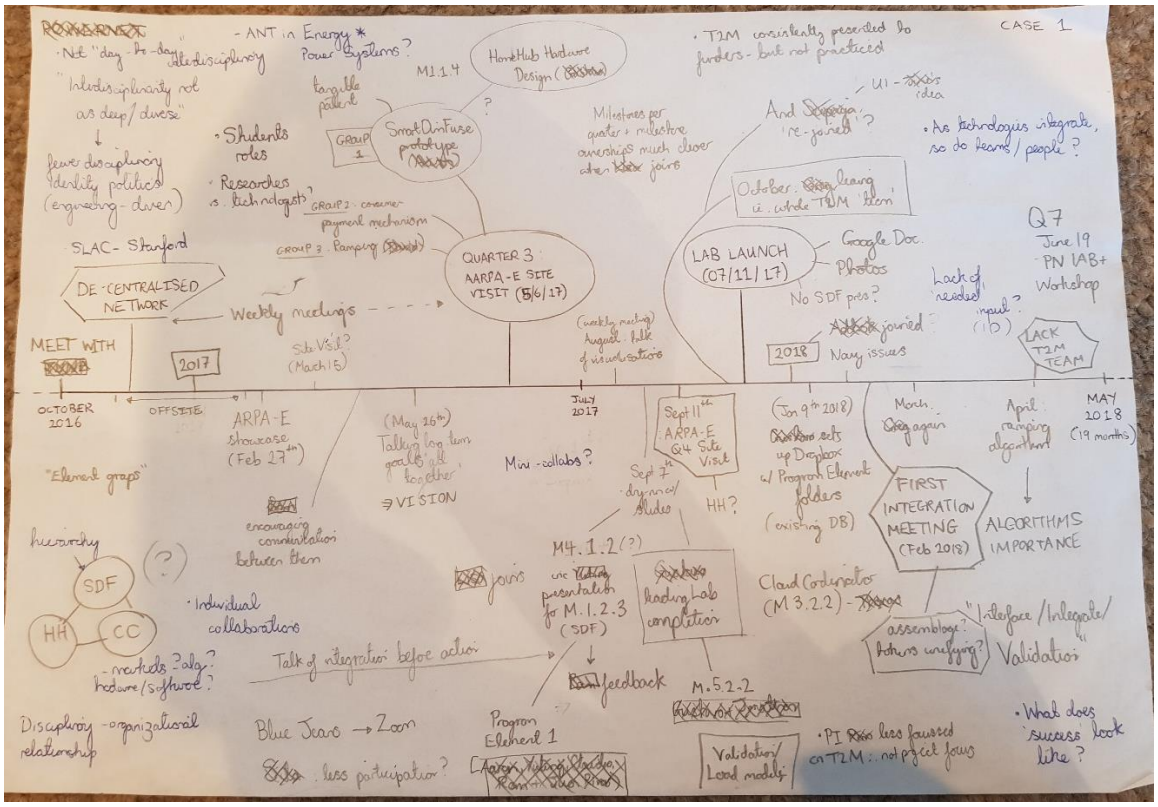


Figure 2. Example chronological hand-drawn project timeline (for CS3)

3.5.1 Narrative choices

The vivid writing style of the Findings chapters in this thesis also participated to a great extent in the data analysis. The value of 'thick description' is prized in ethnography and ANT (Geertz, 1973), and I found that through very detailed description, I could further trace enactments of interdisciplinarity, according to the research question, as I followed actors through the four moments of translation in each case. 'ANT's key contribution is to suggest analytic methods that honour the mess, disorder and ambivalences that order phenomena, including education' (Fenwick and Edwards, 2010: 1), and I seek to '…transcend description and provide explanation whereas the intention of an ANT

sensibility is to provide descriptions' (Wright, 2016: 4). Bardzell and Bardzell (2016: 22) discuss writing as a form of empirical analysis:

> "The act of writing itself often serves as the medium of a writer's thinking; the essayist is not reporting knowledge gained through prior acts, but in some senses is constructing the knowledge in the act of writing. The essay has two key features: It reveals a process of thinking and it is shaped and crafted as a work of writing. The two go hand in hand… Thus, rather than reporting a truth already discovered, as presented in the standard scientific report, the essay can instead be seen as 'enacting the struggle for truth in full view'…"

Indeed, just as 'the interviewer creates the reality of the interview situation' (Denzin and Lincoln, 1994: 353), the methodology I chose, including methods of analysis, 'enacts the reality' of the study: 'Our own stories weave further webs, it is never the case that they simply describe. They too enact realities' (Law, 2009: 154). Praxiography is thus its own intervention on reality, and I became entangled in the projects, both through data collection, analysis and narrative presentation (see chapter 8 for further discussion).

Bowden (2011: 66) argues that '…choices about the method of explanation take analytical precedence over the details of data collection'. Whilst I do not agree with this completely, I think it highlights the importance of my literary choices when writing this thesis, and in particular my writing of the Findings chapters in participating in analysis. Throughout each case narrative, I deliberated over certain words and terminologies, choosing phrasing sensitively and carefully. Firstly, this was to pay attention to the (potential for) agency of non-human actors. In many cases, this materialised in ensuring that I did not represent *only* the human actors as the *subjects* of the verbs, but considered the non-human actors too. Equally, I do not claim to 'give voice' to various study participants, but my narrative seeks to show how instead that such traces relate with each other and with an array of heterogeneous actors, including my own theoretical and methodological choices. Secondly, as I wrote, I found it took a long while to attune to the language of ANT, and

effectively create my own 'toolbox' of ANT language. Crucially, this also included the wording of the central research question, and, as discussed, this went through a number of iterations before I felt the tone to be suitable for an ANT study. Exploring the socio-material practices of technologically-mediated interdisciplinarity in research projects, I found concepts such as 'entanglements', 'embodied practices' and 'resistances' particularly helpful, and this methodological approach will be apparent in the following Findings chapters.

3.6 Ethical Considerations

The research design and methodological framework has raised some ethical considerations. Firstly, whilst I was able to anonymise personal names, as well as the 'official' titles of the projects and of University X, it was difficult to totally anonymise the cases themselves since the nature and context of each project - in particular the nuances of disciplinary 'make-ups', nature of the research and descriptions of technologies - is central to my ethnographically-informed approach. Prior publicity might also impede anonymity of the projects, in particular in the case of the high-profile Digital Humanities project (CS2). In an effort to mitigate risk, whilst offering ethnographic detail, I have included endnotes at the end of this thesis, often references to project websites, which are only available to examiners. Secondly, the sharing of project data outside the boundaries of each research project was a potential concern before entering the field, but I have addressed this by ensuring that no sensitive information is shared from any of the projects, and that all participants fully understood the nature and use of my research (Howe and Moses, 1999).

This project received ethics clearance through the University of Oxford Central University Research Ethics Committee (CUREC), as well as the Institutional Review Board (IRB) of University X, following my successful completion of an online training programme for

nonmedical research (see CUREC and IRB approval in Appendix G).[51] I applied ethical guidelines to mitigate any risk as specified by The British Educational Research Association and The British Sociological Association, as well as The American Educational Research Association. Obtaining ethical approval from University X was a project hurdle; I was originally told I would not need additional ethical approval, and thus the approval took two months to process once I had already arrived in the field. I also had to produce and present to all researcher-participants an IRB Research Consent Form, including potential risks and benefits for participants, alongside the CUREC-specified Participant Information Sheet and Consent Form (see Appendix H). I safeguarded the proper interests of the participants by maintaining transparency throughout. Research only took place with fully-informed consent, and participants were able to withdraw from the study at any time without penalty. Data collected was stored electronically, securely and confidentially according to the Oxford University Information Security policy.

3.6.1 Researcher positionality

I must disclose my personal position shaped by my own educational experiences, and this applies to 'sincerity' within Tracy's (2010) eight big-tent criteria for quality qualitative research. 'I will try to hinge my choices about what to self-disclose around what I think might offer a better understanding of the study informants (human and non-human) and the methodology and ethics of the research context. […] Upon entry into the [the three research projects], what were the initial knowledge practices that mediated my relations with study participants, both human and non-human?' asks vu Henry (2018: 90). I completed a Humanities-based Undergraduate degree at the University of Cambridge and a Master's degree based in the Social Sciences in the Education department at the University of Oxford. Learning throughout the literature review about methodological 'paradigms' tied to particular scholarly disciplines – a topic of concern in STS - has made

[51] The CITI programme includes modules on 'assessing risk' and 'informed consent' (see Appendix I for completion certificate).

me particularly aware of any prior personal conceptual and methodological ties, resulting in a personal methodological reflexivity (Anderson, 2008; Kuhn, 1982). But as Bogdan and Biklen argue (2007: 38), 'being a clean slate is neither possible nor desirable'.[52]

Furthermore, as described in section 3.5.1, familiarising myself and 'getting comfortable' with ANT took me a long time. As well as attuning to the 'slippery-ness' of ANT, as presented in chapter 2 (Literature Review), it took me a while to become at ease with 'viewing' my object of study through a 'post-structuralist' rather than a traditionally 'dualist' lens. My relationship with ANT, at times traumatic, emerged alongside my thesis, and constantly changed and shifted throughout the research process. From my initial research designs, I continued to draw myself closer to ANT as I was in the field, sensitising *my* ANT to the research object of technologically-mediated interdisciplinarity, reacting and acting in real-time to the data I was collecting.[53] As previously discussed, whilst writing the Findings chapters in particular, I found it took a long while to attune to the language of ANT, and effectively create my own 'toolbox' of ANT language. I often deliberated over terminology, choosing phrasing sensitively and carefully. It is particularly important to disclose my relationship with ANT since Thompson and Rimpiläinen (2012: 1) observe that 'not only are approaches to studying these gatherings and heterogeneous processes not well developed, the researcher's toils in this respect are not often evident in ANT accounts'.

3.6.2 Potential limitations and challenges

This study has a few limitations which must be negated as far as possible. The first stems from my use of partial snowball sampling through the preliminary case scoping interviews (section 3.3.1), since I '…inherit the decisions of each individual as to who is suitable… [leading me as] the researcher to collect data which reflect particular perspectives and

[52] Re-visited in Chapter 8.
[53] For example, as detailed in the literature review, I did not find the ANT terms 'actant', 'intermediary' or 'mediator' particularly useful for answering the research question in practice; rather, I found them ANT 'baggage', and as cumbersome on my data collection and analysis.

thereby omit the voices and opinions of others who are not part of a network' (May, 2001: 145). By asking researchers to nominate certain interdisciplinary research projects and researchers, however, I have been able to gain access to research projects and researchers which might otherwise have been unavailable.

A second limitation could come from the inability to generalise a qualitative, collective case study. This research focusses on the US Higher Education sector, making it difficult to generalise internationally; and the University itself has a strong socio-historical culture of innovation, making it difficult to generalise inter-culturally. However, generalisation is not the goal; naturalistic generalisation can nevertheless be used within each individual project, as well as inter-case generalisation if appropriate (Stake, 1994, 2008; Yin, 1989). The aim is to understand the cases rather than to statistically generalise, as Stake (2005: 451) argues that 'potential for learning is a different and sometimes superior criterion to representativeness'. Mills and Morton (2013: 127) suggest that researchers should emphasise the value of 'nuanced, detailed and fine-grained analyses that bring out… complexity… A case is never typical or atypical. Instead it is chosen for the insights it offers into more general issues'. When the research is rich enough, the reader can make choices on interpretation based upon their own intuitive understanding of the particular cases (Stake and Trumball, 1982). Thus, in this study, the conclusions reached should be understood not as the absolute truth, but rather as a result of the most effective methodology which I, as the researcher, have devised to pull myself close the data. Naturalistic generalisation also lessens a third limitation which might come from the lack of control of demographic variables of the participants, which Collins, Bulger and Meyer (2011) call their 'demand-side characteristics'; in other words, the characteristics of researchers which are wrapped up with their work and knowledge practices, outside of their disciplinary 'habits'. There are also limitations and challenges inherent in using the ANT approach, and Law (2007: 65) argues that methods are 'always more or less unruly assemblages', but I have discussed how I will mitigate these potential difficulties.

3.7 Summary

I have laid out the methodological framework for this study, including how research designs were refined in the field, which permits me to 're-evaluate interdisciplinarity' thorough the study's central research question: How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted? Through my selected methodology, the empirical data from the three cases can retain its complexity and heterogeneity. I have discussed the implications of the ANT 'philosophy' on the methodological design of the study, as well as the motivations for choosing the research sites, and methods of data collection and analysis. The research focusses on generating new insights into how technologically-mediated interdisciplinary research happens, and the methods selected will bring to the foreground the 'complex nexus of circumstances bearing on the growth and demise of heterogeneous interdisciplinary assemblages' (Barry and Born, 2013: 41).

Conceptualising interdisciplinarity as practice, and performed by a yet-to-be determined, heterogeneous group of actors, I will now explain how I followed, moment-to-moment, the unfolding socio-material practices of three research and development teams at University X. Following analytical tokens through the moments of translation, I conduct a praxiography of the distributed, heterogeneous, and emergent 'laboratory life' of the projects. In the next three chapters, I narrate my empirical journey, bringing into view enactments of technologically-mediated interdisciplinarity 'in-the-making' across project networks, beginning with that of the 'Medical Robotics' project (CS1).

CHAPTER 4: MEDICAL ROBOTICS FINDINGS (CASE STUDY 1)

4.1 Introduction

My narrative in this chapter describes how an array of humans and non-humans participate in research and technological development in an 'interdisciplinary' project at University X. The Medical Robotics project (2014 - 2018) aims to improve precision during liver radiofrequency ablation (RFA) procedures using robot-assisted needle steering. As an entry point to my investigation, I follow the trajectory of an analytical token, the steerable needle, through four moments of translation (Callon, 1986), in order to explore how technologically-mediated interdisciplinarity is enacted, moment-to-moment, within this case. 'Opening up' the unfolding practices of 'interdisciplinary' research, I explore how shared research aims and technological developments are tackled in practice when different disciplinary 'hinterlands' are brought to bear upon them (Law, 2004).

By tracing how the steerable needle 'gathers' (sometimes temporary and partial) enrolments of actors as allies into this particular project actor-network, I aim to bring to the fore the entwined practices around the 'co-production' and development of a (medical) socio-material assemblage (Jasanoff, 2016). First, I frame how *problematisation* came about, articulated in the successful project grant proposal, before I joined the project-actor-network. Next, I explore the second moment of translation, *interessement*, as actors are drawn towards the framing of the Medical Robotics project and its research aims. Finally, in the latter two moments of translation, *enrolment* and *mobilisation*, my narrative will focus on the 'Zeevo' experiments as a site of interdisciplinary negotiations and trials of strength. I will describe how, when multiple ontologies coordinate in different ways, (partial) translation is brought about.[54] ANT sensibilities help me attend to, and

[54] By coordination, I reject Crawford's (2004) definition as the '..adoption of convention, codification and translation', and rather subscribe to Mol's (2010: 264) framing: 'The term coordination suggests continuing effort. Tensions live on and gaps must be bridged…'.

interfere with, processes of (un)settling differently enacted realities in this interdisciplinary project.

I describe how, during the four moments of translation in the Medical Robotics project, ontologies entangle and dis-entangle as 'messy', situated interdisciplinarities (and disciplinarities) are enacted at different times. Differences are (un)settled and (re)configured, disciplines coalesce, hang together and break apart; interdisciplinarities co-exist. As technology is produced, so too are sets of social relations and hierarchies (Law, 1992), and this is about which 'realities-in-the-making' are privileged 'when there are inconsistencies' (Oliver, 2012: 443; Woolgar and Lezaun, 2013). The narrative will explore how the 'privileging' of realities comes about in this case; how the network comes together, or not, around the steerable needle, in the midst of constantly shifting relations; and how this heterogeneous research team (both human and non-human) enacts technologically-mediated interdisciplinarity. What can we make of 'interdisciplinary-in-the-making' in this case?

4.2 Problematisation

The empirical account begins with the first moment of translation. I describe how two of the researchers in the project team, Andrea [the 'heterogenous engineer' (Law, 1992)] and Mina, a clinician, formulated a problematisation that was reified in a project grant application, before I entered the field. I frame the establishment of the research aims for the project as Obligatory Points of Passage, or OPPs (Callon, 1986), which fixed the initial parameters for my cutting, or bounding, of the network that I call the Medical Robotics project (Strathern, 1996). I must state at this point that it may seem unorthodox to situate the point of problematisation a number of years prior to my joining the project. However, there is, at any given point during translation, 'an abundance of problematisations' (Callon, 1980: 199), whereby many different actors simultaneously attempt to conduct negotiations to promote their own interests. In situating my analysis of problematisation principally from the position of the researchers Andrea and Mina, before I joined the

team, I do not assert the 'ontological primacy' of their practices and approaches in relation to others (Callon, 1980: 389), nor do I privilege the human. Problematisation is presented '…as a hypothetical formulation that is imposed by a given [actor] and eventually weakened, confirmed, or transformed by others as a socio-material assemblage is enacted' (Callon, 1986: 228). It is not therefore an ontological claim on my part about the 'real' identities and interests of the actors (at any given point). Furthermore, it is key to note that the problematisation I describe can be actualised, and has the 'capacity' to translate, in potentially numerous different ways. I choose to follow one such process of translation as brought into focus by the needle as the analytical token - one which can productively bring technologically-mediated interdisciplinary practice to the foreground.

4.2.1 A doctor and an engineer formulate a problem

Andrea, Professor in the Mechanical Engineering department at University X, the PI of the Medical Robotics project, and the director of the Robotics lab where the project is 'housed', was accompanied by a steerable needle from her previous University, to her appointment at University X in 2011. It was a few years later that she met and decided to collaborate with Mina, an interventional radiologist at the hospital of University X. Joseph,[55] a graduate student in Mechanical Engineering who had previously built the software which helps to process ultrasound images acquired during the project, explained to me that:

> "Andrea came to [University X] from [University W], and was like 'I like doing medical robotics', but she didn't have very many clinical collaborators… [So she] went to the medical school [at University X] and started having blind dates with doctors, essentially, 'here's what we do, here's what you do - what needs do you have?', and steerable needles was one of the things they had said – 'hey we've got this technology'. So, at some point she met Mina in this blind date process…[and]

[55] Joseph describes himself as 'knowledge transfer' when 'handing over' the project to a postgraduate student Jennifer (who will be introduced soon), and whom Jennifer describes as 'her shoulder'.

> they somehow said this would be a great application of this technology – steerable needles to liver ablation… it was a hammer looking for a nail" (Joseph)

Pete, an interventional radiologist like Mina, who will be drawn into the network during the second moment of translation, added:

> "Mina and Andrea had been collaborating on this project, or on the predecessor to this… and I think they had reached the conclusion that the robotic technology was fascinating, but the difficulty in getting it funded or moving it forward was really a clinical problem, clinical application." (Pete)

Therefore, a research proposal was devised which drew together the steerable needle and accompanying robotic technology with a clinical application. The researchers Andrea and Mina converged to fix the 'initial parameters of a solution' that was put forward in the research aims of the proposal, reifying a prospective alliance of different actors, and setting the stage for the (interdisciplinary) entanglements that unfold in the three subsequent sections on interessement, enrolment, and mobilisation in this chapter. According to the 'official' Medical Robotics project grant proposal:

> "…the long-term goal of this work is to significantly improve access, accuracy, and precision during percutaneous liver radiofrequency ablation (RFA) procedures using robot-assisted needle steering. The following specific aims will enable the development of this technology and demonstrate feasibility, as a path to clinical adoption: (1) Optimise ultrasound-based localisation of highly curved needles and closed-loop control of robotic needle steering; (2) Develop an interactive user control interface and enable teleoperated needle steering intervention; (3) Design a clinical robot-assisted needle steering system for percutaneous liver RFA, validated in an ex vivo liver model; and (4) Validate the ultrasound-guided needle steering system in vivo in porcine liver."

Alongside goals to improve needle precision during RFA procedures, and to validate its potential for clinical adoption, the proposal sets out to develop the use of ultrasound for needle location. It is therefore important to note, during this first moment of translation, that the nature of imaging, in particular the use of ultrasound (as well as the 'traditional' clinical method of CT scanning), is 'active' in the network at an early stage. As such, since a long-term aim of the project is to work towards making CT scans obsolete for liver ablation procedures, favouring the 'lower tech' option of ultrasound,[56] then the fulfilment of this goal would presumably lead to one outcome of 'success' for the project.[57] It will therefore be interesting to trace through the four moments whether the network *can* stabilise with a mobilisation of CT; and whether there will be a heavier focus on either the development of the needle technology, or the imaging component.

Through the grant proposal, Andrea and Mina engaged in the inter-definition of the actors which they wished to draw into the project. Mina, the radiologist, elaborated upon on her position during this problematisation:

> "I feel like my main role is to provide some clinical foundation to what Andrea's team is working on [...] I think one of my first contributions was coming up with an idea for how that technology could be clinically applicable, and then what I thought might be the limitations for a technology like that. And in terms of clinically applicable, we discussed what potential unmet needs would be in terms of getting a needle from point A to point B, and where being able to steer a curved needle might prove useful. Then it was a back and forth discussion about tissue texture and what parts of the body this needle could work in." (Mina)[58]

[56] CT imaging is used here to support and validate – as a 'ground truth' - for ultrasound imaging.
[57] Grappling with framing project 'success' (and to whom this might 'belong'), alongside its relationship with translation and mobilisation, takes place throughout the thesis.
[58] Mina's reference to 'Andrea's team' suggests ideas of project ownership, as well as self-conscious 'level of embeddedness' in the project, which I will explore later in this chapter (particularly concerning Selena).

As with the other two cases, technological development is inextricably linked with the research aims. The point of problematisation here 'starts' the potential of translating the research aims into practices of research, technology and other outputs. The research aims and intended technological output represent Mina and Andrea's shared, interdisciplinary 'imagined futures' (Jasanoff and Kim, 2015). Indeed, it is here that the research grant proposal begins to entangle the (inter)disciplines of robotics and medicine, and their human 'spokespersons'. It could even be argued that this proposal, an inscription (Akrich and Latour, 1992),[59] represents a mobilisation and (interdisciplinary) translation of their respective *disciplinary* imaginaries – and it is this translation that also forms the point of problematisation in my narrative. The needle, as it is situated in the proposal (the OPP), will begin to draw together the established disciplinary fields of robotics (embedded within engineering here) and medicine - a dichotomy which does not disappear in the minds of the human researchers during the project:

> "One of the strengths that I have in having both a clinical and a technical training is that I can sort of bridge the gap between the worlds. So my font of knowledge on the technical side is not as deep as Andrea's or Jennifer's - they certainly understand that much better than I do - but I can help them bridge the gap on what's really important or relevant from a clinical standpoint… I can help take the work that they do and help make it relevant, and then help translate it to actually be used in patients." (Pete)

> "Focussing from the engineering perspective on my end, [I pitched] crazy ideas and… the clinicians [would say] 'woah woah, what you're saying that's ridiculous…' It's usually the engineer in my experience [who] pitches something that's too complicated, and the clinicians say, 'we don't need it to be so technologically great, we just need it to work'… [Clinicians and engineers] just approach it from such different perspectives. Engineers of course we want to make the coolest thing, and

[59] See later in this chapter for a more in-depth discussion of inscriptions.

> so we have this tendency to overdesign, and then the clinicians of course want to do ground-breaking medical research - they're the user of the technology and sometimes guiding the technology, so it's fundamentally different motivations - more than just knowledge - it's different rewards, different ways the rewards systems are structured around the process."[60] (Joseph)

It is important to re-iterate at this point, as previously discussed in the Methodology chapter, that I use my sources of data in a number of different ways. I explore the 'silent' *and* embodied instantiations of 'doing interdisciplinarity', as well as the spoken reflections and insights of researchers and practitioners (Mulcahy, 2013). Of particular importance here is my use of interview data not only to establish 'historical context' and to ascertain 'what happened' in the lived experiences of the human researchers, but also to understand their personal approaches to and opinions on interdisciplinarity as it is enacted. There was a prevalent view generally held by the human researchers across this case regarding what I term 'dichotomous worlds'; in other words, the researchers have a strong tendency to view a prominent division, dualism and relative detachment, between the mechanical/technical/engineering and the clinical/medical in the project. Alongside this, as illustrated through Pete's comment above regarding the 'depth' of knowledge in a field, there is a sensitivity towards 'understanding' in the project, versus 'acknowledging' with more of a cursory, or 'surface-level' comprehension. Articulations around 'bridging the gap' between 'thinking like a doctor' versus 'thinking like an engineer' suggest traditional, clear-cut 'disciplinary views' held by the researchers, whether they are discussing crossing these 'boundaries', or 'staying on my side'. Counter to this point, Mina told me that '…interventional radiologists actually think a lot like engineers, we're always trying to fix

[60] The clinicians' dual role as the co-developer *and* 'radiologist-user' of the technology is notable: 'I think a lot about the devices and equipment I use in my research and in clinical practice. I think that working on them and researching them, you understand your tools in a much deeper way than you do if you're literally just practicing medicine, and you're buying a needle to do something. I actually think about the stiffness, and strain, and tensile strength, all of these things, and I think about how that matters in how I practice…. My research on these devices makes me think differently about them in how I practice.' (Pete) (see Chapter 8 for further discussion)

things…so I feel like we are kind of birds of a feather even though we are very differently trained', but nevertheless, Pete disagreed, explaining that:

> "I think the one thing I love about working with [engineers] is it kind of forces me to think like an engineer when I'm approaching my research, and I sort of feel like I can bridge both worlds having both a clinical and a technical background, but I think that engineers approach [problems] very differently than doctors do. I like to think that I'm a little bit more methodical and systematic about my approach to things because I do so many projects with physicists and engineers… I've learned a lot from my engineering colleagues over the years." (Pete)

Whilst Pete discusses his self-perceived adaptability across these disciplines, there is a level of 'comfort', as might be expected, for most of the other researchers in their 'home discipline' methods, motivations, priorities and areas of application. Interestingly, however, they do not always describe these as 'disciplinary', favouring terms such as expertise, experiences, skillsets, competencies, and 'approaches'. Indeed, the researchers' disciplinary 'hinterlands' (Law, 2004) – what I define as assemblages comprised of expertise, experiences and approaches - participate in generating the reality that they study; that is, their 'reality-in-the-making'.

4.2.2 The steerable needle: robotics to radiology

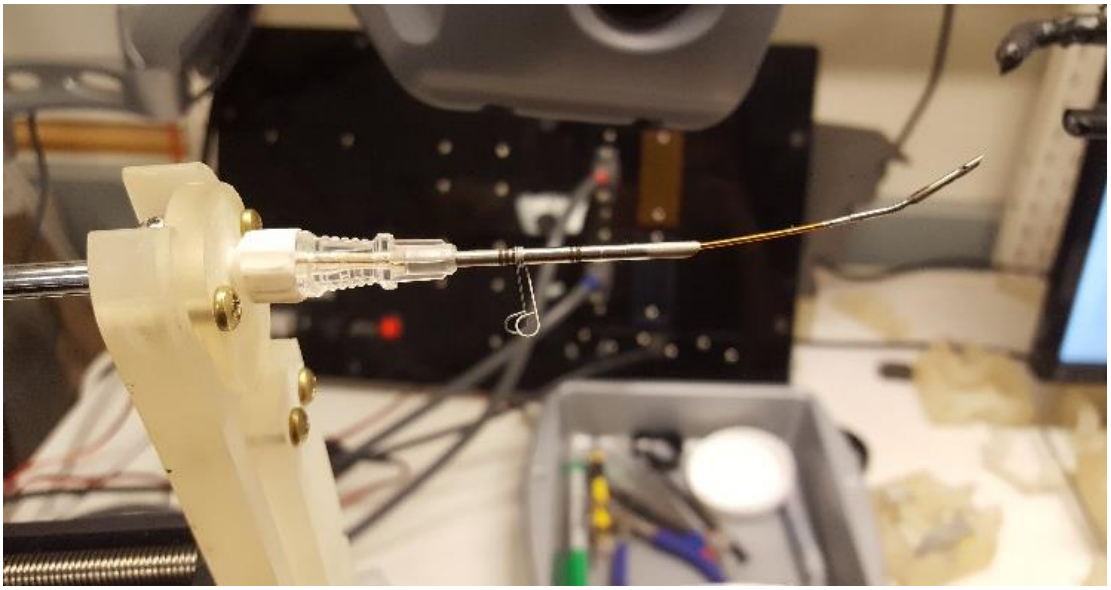


Figure 3. The steerable needle in the Robotics lab (Photo by Erin Young)

As I joined the Medical Robotics project in March 2017, 2.5 years after the funding was granted, a prototype of the steerable needle was already present (having already fully enrolled in an adjacent actor-network, but one which is not my focus). As mentioned above, the prototyping of the steerable needle itself had in fact been in development for a number of years prior to the Medical Robotics project's official launch in 2014. It is this needle, 'the hammer for the nail', which 'found its application' to medicine at the point of problematisation. However, the most recent iteration of the steerable needle (see figure 3) - at the centre of the web of relations in this narrative - was not black-boxed at the point of problematisation. The grant proposal abstract explains that:

> '…needle steering enables the insertion of highly flexible needles or guidewires along controlled, curved, 3D paths through tissue. Thus, the needle can be actively steered to acquire tumours not accessible by a straight-line path, and unexpected deviations from the desired path can be corrected as the needle advances toward the tumour. A functional needle steering system appropriate for in vivo experimentation must be compatible with widely available medical imaging (here, ultrasound imaging), have the ability to deliver treatment (here, RFA through the

> use of a steerable needle electrode), and an appropriate user interface including visualisation and human-in-the-loop teleoperation.'[61]

It is also interesting to note at this point that upon being drawn towards this particular Medical Robotics actor-network, the needle also represented a point of mobilisation of an actor-network from Andrea's previous hospital, as it (or a version of it) translated alongside Andrea's and Mina's 'imagined future' into the grant proposal:

> "… it started out as basically a robotics project [but] this is something surgeons had known for a long time, that sometimes you can get these needles to steer when they're flexible and have this bend at the end. But the early stages were a bunch of roboticists… it was really a robotics project where robotics people were dreaming, essentially, making up challenges for themselves… there were a lot of theoretical papers… Basically it spawned an entire sub-field of robotics research… [and Andrea] was sort of on the ground floor of that… [Then] people said, 'Okay so we had our fun [in the] robotics world doing the theory and making this a robotics problem, but we need to start applying this to more medical [areas and] delivering on the promise of steerable needles. We'd like to start targeting clinical applications of this technology." (Joseph)

At the end of problematisation, the grant proposal possibilities are only that – 'the entities identified and the relationships envisaged have not been tested' (Callon, 1986: 8). Mina and Andrea's provisional interdisciplinary 'system of alliances, or associations, between entities, thereby defining their identity and what they want' remains a proposition (Callon, 1986: 203). Additional negotiations and materials will be required to move reality closer to their intentions; these negotiations are introduced in the next section, as part of my account of the second moment of translation, interessement (Callon, 1986). During this phase, additional human and non-human actors will be incorporated to draw allies closer

[61] Taken from the project proposal.

to the project. One of these devices of interessement is the steerable needle, which we have already met as the analytical token to trace the enactment of technologically-mediated interdisciplinary practice in this project.

4.2.3 A brief note to 'departed' actors

I mention at this point the human researchers who 'left' the Medical Robotics project before I joined; that is, those who were engaged in, and therefore shaped, the project following the point of problematisation. I made an explicit methodological choice to gain access to and interview Joseph (who I have already introduced) and Troy, postgraduate students, as well as Sophie, a graduate student, with the rationale that this was important in elucidating decisions made and actions taken within the actor-network which this narrative traces. Whilst I will not go into depth, it is important to touch upon them since their presence will have shaped what I encounter through the needle's journey. For example, Joseph explains that, 'I'm fundamentally a software guy, so I have no mechanical skills whatsoever really. So I don't do anything working with my hands, it's just not my strong point. Jennifer is almost the exact opposite where her real strong point is mechanical design… When Troy left, we realised I was not going to be able to do the mechanical stuff required for the project,' adding, 'I wasn't interested in a clinical PhD, whereas Jennifer had this great clinical background and that's what she's interested in.' By contrasting himself with Jennifer (who took over Troy's role on the project), it is further suggested the extent to which the researchers' 'comfort in' and loyalty to their home disciplines shapes (and in turn, is shaped by) the interdisciplinary enactments we see across the course of my narrative. Furthermore, Sophie, a PhD student at University X and a rotator on the project for a few months,[62] explained to me that she thought her contributions on the project were 'pretty minimal', supporting the narrative I was building around the researchers' ideas of levels of project 'ownership', and being central or

[62] The first-year PhD rotation programme at University X allows for first-year students in certain PhD programmes to move labs or research groups a few times before deciding upon their permanent advisor.

periphery to the project, which I will explore later in this chapter. Not to privilege the human experience, I now turn my attention back to the steerable needle, brought into focus at the point of problematisation, and next elaborated upon as a device of interessement.

4.3 Interessement

During the second moment of translation, a variety of material devices of interessement are assembled to 'extend and materialise the hypothesis made by the researchers' (Callon, 1986: 9). The heterogeneous engineers (Andrea and Mina) enlist these devices of interessement in an attempt to begin to 'impose and stabilise the identity of the other actors' (Callon, 1986: 207-208), in closer alignment with their own goals, which frame the research project. 'Interessement helps corner the entities to be enrolled,' but 'success is never assured… the device of interessement does not necessarily lead to alliances, that is, to actual enrolment' (Callon, 1986: 211). I therefore conceive of interessement as a 'potential gathering'; not one moment or action, but rather a moving entity, difficult to pin down. Although Callon (1986) delineates between the four moments of translation, in accordance with my application of ANT to explore the complexities of the Medical Robotics project network, I describe a lengthy period of prolonged hesitation, that is, a 'stalling' or 'wavering'. In other words, the actors spend a long time negotiating the terms of their enrolment, perhaps partially enrolling, and then re-negotiating again, re-interessing, in a somewhat cyclical process. Whilst I must be careful not to equate Callon's four moments with strict temporal passing - and a number of translations, potentially numerous, of the problematisation presented above may have taken place previously - it is during this 'wavering' that I joined the Medical Robotics project. I describe how the research aims were solidified as an Obligatory Passage Point (OPP) through the incorporation of additional human and non-human actors. I show how activities brought the steerable needle to bear on the interdisciplinarity of the Medical Robotics project, and how it drew other actors and their interests closer to the project plan.

4.3.1 The needle: bound with Jennifer as co-devices of interessement

In the case of the Medical Robotics project actor-network that this narrative follows, the analytic token, the steerable needle, although already 'present' at the point of problematisation, is framed as a key device of interessement, shaping how other enlisted actors are drawn into the project. But it is not alone in this: the steerable needle forms a 'tightly-knit' 'almost-assemblage' with Jennifer, a postdoctoral engineer on the project, who might even be labelled a 'co-device of interessement' due to her central 'position' in the network. Jennifer, who joined the project two years after it was funded, is viewed by the majority of the human researchers as having 'ownership' of the project (including by herself), despite the fact that she was not present at the point of problematisation (and did not contribute to the research proposal); 'The whole contribution everyone is going to have on the project will not be as much as mine,' she told me. Jennifer identifies primarily as a biomedical engineer:

> "My background is biomedical engineering, so I'm not really mechanical engineering. I studied both mechanical and electrical engineering, and informatics also. Not that much though - I have always specialised on the mechanical design side of medical devices. I know *something* about electronics and informatics, but I wouldn't say I'm an expert. That's why I'm using the support of other people. I specialise in this sector of surgical robotics which is using robotics for medical purposes…" (Jennifer)

Notably, she is the only researcher officially working on the project full-time, and when I joined the project her day-to-day focus was in the Robotics lab, the lab directed by the PI Andrea, and as mentioned, 'home' to the Medical Robotics project. Jennifer continuously 'tweaked' the needle as it incorporated into the wider technological system that the project is aiming to build, and her design choices are integrated with the needle:

> "I'm working on controlling the needle, a different kind of work with respect to the mechanical design. At the beginning [of my time on the project] it was really

> frustrating because I was not building the whole platform from scratch – I was controlling something that was done by [Troy] who wasn't here anymore. Sometimes I also still find problems… I spent almost two months fixing a problem which wasn't really the problem! I had to change more than half the components because I thought the problem was a mechanical issue, which I'm more used to dealing with, but it was actually an electrical one" (Jennifer)

Working in the Robotics lab, and as shown in figure 4, the needle and Jennifer interesse the robotic arm, ultrasound, the software and phantom tissue, among a number of other actors, some of which will proceed to enrol into the actor-network during the next moment of translation, and some of which will not.

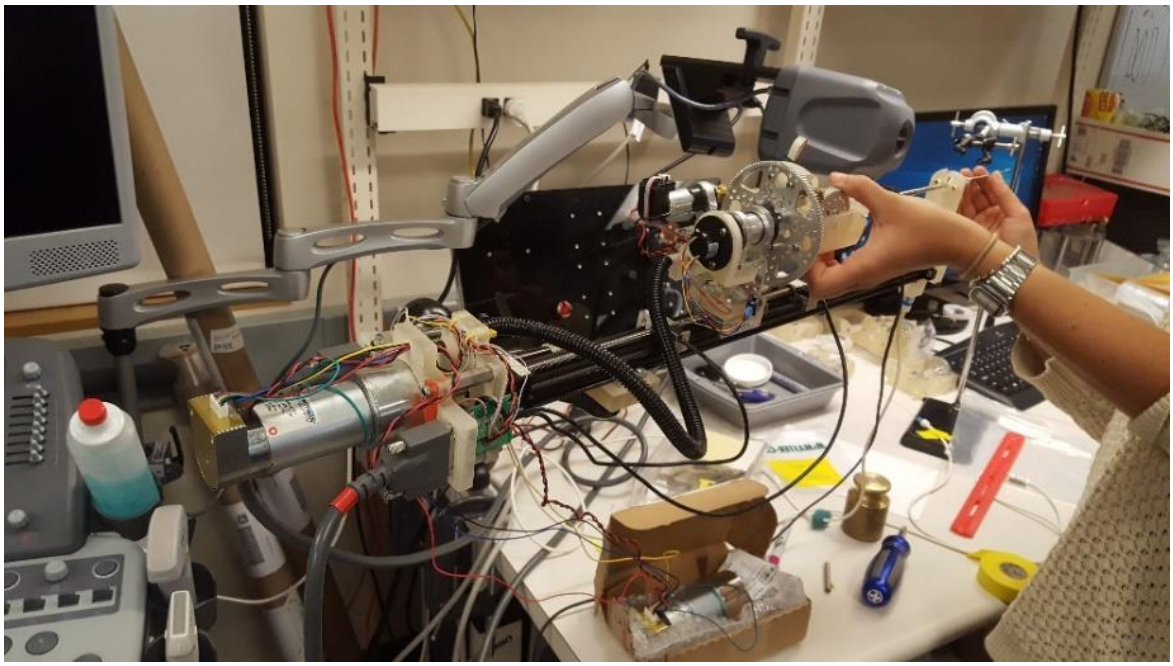


Figure 4. Robotic assemblage with needle in the Robotics lab (Photo by Erin Young)

4.3.2 Interessing Pete: prolonged negotiations between medicine and engineering

I have already introduced Mina, an interventional radiologist and a major contributor to the grant proposal; now I introduce Pete, another interventional radiologist, as he joined negotiations in the Medical Robotics project. Pete was Mina's resident, her fellow in

interventional radiology, and it was she who initially thought to invite Pete to collaborate on the project. She explained to me that, 'Pete had the background from his PhD work to tell us how to rig the needle to become a very rudimentary ablation needle. And because I knew that he was interested in ablation, and because he was going to continue on in a research career, I thought it would be helpful to [bring him in]'. She adds, 'He probably is a better bridge to the technical aspects than I am because he thinks like an engineer; he's had engineering training and has an engineering degree, whereas I don't have any of that!' (Mina). Though primarily an interventional radiologist, Pete has a PhD in biomedical engineering, and has co-founded medical device and ablation companies. 'I'm just inherently curious and interested', he tells me, adding, 'I helped come up with the concept of marrying the steerable needle approach to an ablative application on this project'. He describes his background as interdisciplinary:

> "The interesting thing about my specialty in interventional radiology is that, basically every research project I'm on is in some ways interdisciplinary. I collaborate on almost every project I'm doing with medical physicists, biomedical engineers, mechanical engineers, electrical engineers, and with other biomedical scientists, like bio-chemists, so I collaborate quite a bit. A lot of my research efforts are on… doing advanced imaging, so those are all with people in different disciplines, albeit somewhat related - most are fairly technical - but they're all different." (Pete)

Since Pete is not located at University X, Jennifer and Pete run a series of Skype meetings to discuss the development of the steerable needle and its robotic platform. It is during these periodic discussions, some of which I attended on Jennifer's side of the call, that Pete's role in the project is negotiated:

> "Early on Jennifer and I talked a lot about constraints or design choices related specifically to the technology, to the types of desired outcomes for the ablation, the ways that it could be implemented. I think particularly over the last months there's

been a lot of work on the control and some of the feedback with the robotics which is certainly not my expertise. As of late my role has been much more of a consulting role, whereby we have these types of conversations which allow [Jennifer] to re-bound ideas off me. For example, we were talking about the length of an iterative step for needle insertion and what would be clinically acceptable, reasonable [and] feasible…" (Pete)

Not only does this suggest how the needle simultaneously shapes and is shaped by other actors to enact interdisciplinary practice during the second moment of translation, but moreover this shows how the roles of the radiologists, both Mina and Pete, shift during this period of hesitation around interessement. As I will discuss in the next stage of translation, even during the upcoming Zeevo experiments, tensions around defining and establishing the role of the clinicians in the, up to this time, 'engineering-led' project are apparent:

"If you are seen as a consultant, you'll be brought in only when people feel like they need your help. And what ends up happening is assumptions are made about how up to speed you are on a project. And so they'll start talking about things, and I'm like, 'I don't even know what you're talking about! You realise, that was the last 3 months of work that we haven't talked about and I'm supposed to pick right up and run with it!' I don't find it to be a big deal, but you just have to say, 'remember we haven't engaged this quarter, so we've just got to talk about that'. But I also think the problem with that is there are missed opportunities to get input on both sides, and I think when you're physically present, there tends to be more regularly scheduled contact - maybe that's one of the challenges in working in these types of groups or environments. And you could solve that, you could do a weekly conference call, but people's schedules get in the way." (Pete)

This prolonged interessement of Pete is not only suggested through the (sometimes) difficulty of his communication with Jennifer and the rest of the researchers, but also in his desired outputs and foci for the project:

> "[Pete] was objecting to the fact that radiofrequency ablation is not the most advanced way to ablate a tissue because nowadays there are other techniques like microwave ablation - even though radiofrequency ablation is most used still**.** He was worried about, if you do a publication and a reviewer is a radiologist who is only interested in the type of ablation. They're not going to be focussed on the fact that you are reaching a point you couldn't reach, but more about the shape of the ablation… – which is actually not something that we worked on, because that is not our objective. We are working on a needle to reach a difficult place in a minimally invasive way." (Jennifer)

Here, Jennifer explains that Pete was focussing on the method of ablation of the needle, within the research aims, whilst she was much more interested in the mechanical curvature of the needle. Whilst this might traditionally be understood as competing perspectives, these negotiations during interessement suggest the enactment of multiple (disciplinary) realities which hang together uncomfortably around the steerable needle. A similar tension is worth noting here, as reflected upon by Mina, as she explains how the physicality of the steerable needle itself is contested between the radiologists and the engineers from an early stage in the project:

> "The project [is] driven by engineers, so we'd have to say, time out, this is not how a physician would want to go about doing this, or, these are the concerns a physician would have about things like needle migration or placement or procedure times or paralysing patients, and things like that. I remember one of the first discussions I had [with a previous postgraduate researcher on the project]… he said, 'we're going to need to use a 13, maybe an 11-gauge needle'. [And I said] 'you know, doctors aren't going to want to stick 11-gauge needles into their

> patients' bodies - that's a big hole and it will increase the bleeding risk'… For [the engineers], it's like, 'oh it's a little bigger' - well no actually it's a lot bigger, it actually makes a huge difference!" (Mina).

Similarly, Pete explained that to me, during an observation, that 'we use smaller needles for an ablation…[this size] is used for bone'. Pete's prolonged interessement thus emerges in part from these competing realities, which also contributes to his not feeling 'in-the-loop' with the project as a whole.

Indeed, as I mentioned previously, there is a general (lack of) project ownership for the researchers, as identified through their in-depth interviews. Pete explained that, 'there's a lot of work being done that I'm not intimately or directly involved with, which is different to what I'm used to – like all of the control algorithm development for the robot, and a lot of the design for the articulating'. Joseph, however, told me that, 'I think that for a medical robotics system to work, the engineers need to be in the hospital and have this tight feedback loop. It doesn't work to meet once every 3 months…I think you need a really tight collaboration'. Indeed, it seems that the needle's development has been primarily 'engineer-led' thus far, through the first two moments of translation. 'The team in our lab who is really working on the project, we are mainly engineers [but] the help that we get in developing the validation tests, it's really coming from the medical personnel… They are both radiologists so they perform radiofrequency ablation with needles which are straight [and] they work on finding the best straight path to the target with the traditional method, using CT scans and sometimes ultrasound' (Jennifer). In other words, there is a *potential* 'imposition' of an engineer's emerging ontology, a 'reality-in-the-making' - early 'trials of strength' and struggles between ontologies, perhaps – and it is this which I will continue to explore as my narrative reaches the third moment of translation, enrolment.

4.3.3 A brief note on an article

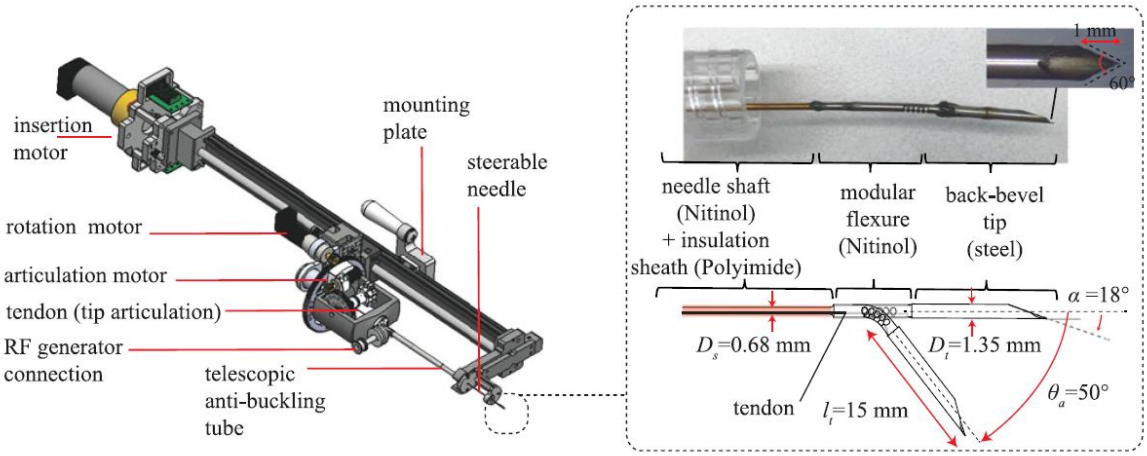


Figure 5. Overview of the robotic needle steering platform 'assemblage', and a magnified view of the needle tip (Gerboni et al., 2017).

A research article, co-written by five members of the research team (three engineers and two doctors), must be briefly presented at this point in the narrative. Produced after a long period of work with the steerable needle and the robotic system in the Robotics lab, this represents a (prior) translation of an (overlapping) actor-network. Figure 5 is drawn from the article, detailing some of the mechanical properties of the needle; other parts of the article explain the material characteristics of this needle. As stated, it provides '…a description of the clinical challenges…[alongside] the design requirements for an effective robotic needle steering system [with]… an overview of the needle steering robotic system' (Gerboni et al., 2017: 1368). This, as I call it, 'single narrative' articulation of both the clinical and the engineering elements of the project, during inscription of the translation into this article (Akrich and Latour, 1992), suggests the '…pressures in the research team to produce a singular account from this multiplicity rather than represent the multiple ontologies of research practices' (Fenwick and Edwards, 2010: 158). Indeed, whilst writing an upcoming article, Jennifer told me that '…when you're able to do an animal test with a robotic protype, you can aim at Nature, biomedical engineering, these type of publications, and you can get doctors [and] you get engineers [reviewing the articles]…

you can get both…". Different disciplinary realities hang together within this article, representing how 'robotic surgery suggests a complicated terrain where the nature of the human and the machine bleed into each other' (Olson, 2009: iii).

'The practice of interdisciplinarity is variously social, material and textual', argues Mulcahy (2013: 6). This article is black-boxed in the actor-network which my narrative follows; it is an interdisciplinary object, an interdisciplinary enactment as a result of a translation, circulating through the network. Indeed, as will be re-visited during the final moment of translation in this chapter, a translation presupposes a medium or a 'material into which it is inscribed', and translations can be 'embodied in texts, machines [and] bodily skills [or work procedures]' (Callon, 1991: 143). This article inscription attempts to define a framework for possible future action, and it is with this potential framework that the narrative moves to the third moment of translation.

4.4 Enrolment, or (inter)disciplinary negotiations, ontological co-ordinations and (dis)entanglements

I have described a period of prolonged hesitation during the four moments of translation as conceived by Callon (1986). I re-iterate here that, despite his delineation between these moments, the boundary between interessement and enrolment, in the case of the Medical Robotics project at least, is less distinct. As I begin my narrative of the period of enrolment, I will look at whether or not, and to what extent, actors I have already introduced - including some which I will bring to attention in this section - 'accept' the roles that have been defined for them during interessement, engaging in new identities and behaviours (Fenwick and Edwards, 2010). This is about interrelations between, or lack thereof, the roles which have been tentatively allocated to the actors. My account continues to follow the needle, exploring the extent to which it participates in consolidating the alliances that were initially envisioned by Andrea and Mina. However, I challenge the notion of 'role acceptance' as too passive, particularly when used as a concept within a framing such as ANT which purports agency, or at least the potential for

agency, of all actors. Therefore, (full and partial, temporary and more permanent) enrolment is presented here as a series of negotiations, configurations and tensions, particularly around the steerable needle, aimed at 'resolving' the conflicting ontological politics that unfold during the technological development and research experiments within this case (Mol, 1999: 79).

During this third moment of translation, I describe how multiple enacted ontologies coordinate towards translation. I illustrate how trials of strength (Latour, 1987) during this period of enrolment could be attributed to the multiplicity of the steerable needle, according to the multiplicity of ontologies which co-exist, and the (inter/disciplinary) ontological politics associated with the needle's fluidity (Mol, 1999). If there are multiple needles, then it follows that there may be multiple actor-networks overlapping and interfering with one another, and my narrative aims to honour this complexity, whilst exploring the instances of the actor-network which it follows. Ontologies entangle and dis-entangle, jostle and negotiate in the space of the Zeevo lab; differences are (un)settled and (re)configured, and realities-in-the-making are 'realised', displaced and marginalised. Actors (and disciplines) coalesce, forming alliances, hanging together, or breaking apart. This stage reflects a struggle to determine the ontologies - the 'constellations of divergent and wide-ranging knowledge practices' (vu Henry, 2018) - that will prevail in the enactment of interdisciplinarity during the next and final stage of translation, mobilisation. The narrative of this moment thus explores how actors negotiate ontological politics as their disciplinarities and interdisciplinarities unfold in practice, including what resists and who enrols.

4.4.1 Enrolling the 'Zeevo' lab: the accommodation of new actors

We join the Medical Robotics project again as experiments in the Zeevo lab begin. Whilst there has been entanglement of the (inter)disciplines of robotics and medicine from the point of problematisation, these experiments represent the time during my fieldwork when the greatest number of participant-actors – both human and non-human –

physically came together in a space. This was in large part a rationale for my choice not only to undertake a number of observations in the lab, having been granted security clearance, but also to centre this part of the narrative of the third moment of translation within the lab's space. The Zeevo lab is enrolled into the actor-network as a space for experimentation (for validation of the robot-assisted needle steering system as laid out in the project proposal), and thus was further deemed as the most suitable space to explore multiple enrolments and potential barriers to enrolment. With its own enrolment, the lab also interesses and enrols, to differing extents, its material 'contents': the 'Zeevo' machine (an industry-developed, multi-axis system for interventional imaging consisting of a large C-arm to X-ray), numerous computer screens, CT software, benchtops and stools, alongside multiple other actors, as can be seen below in figures 6 - 9. The presence of the C-arm for CT scans, alongside the imminent introduction of the ultrasound machine to the space, will bring to the fore the development of imaging techniques which were introduced in the project proposal – and how they might participate into multiple realities-in-the-making. It is the space where the two main technical challenges set out in the proposal – developing the steerable needle's robotic technology, as well as the use of 'lower tech' ultrasound imaging to determine its accuracy – are drawn together amidst the ever-shifting complexities of the Medical Robotics actor-network.

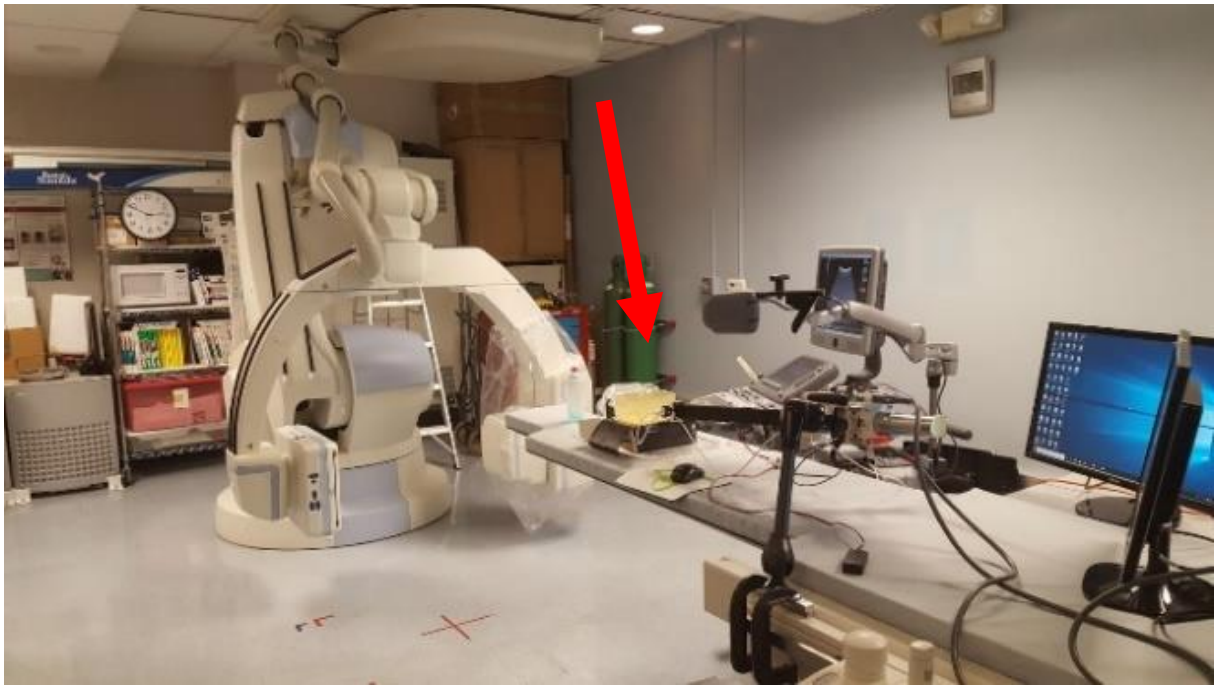


Figure 6. The Zeevo lab, with the needle in agar jelly highlighted towards the centre-right (Photo by Erin Young)



Figure 7. The Zeevo lab, view 2 (Photo by Erin Young)

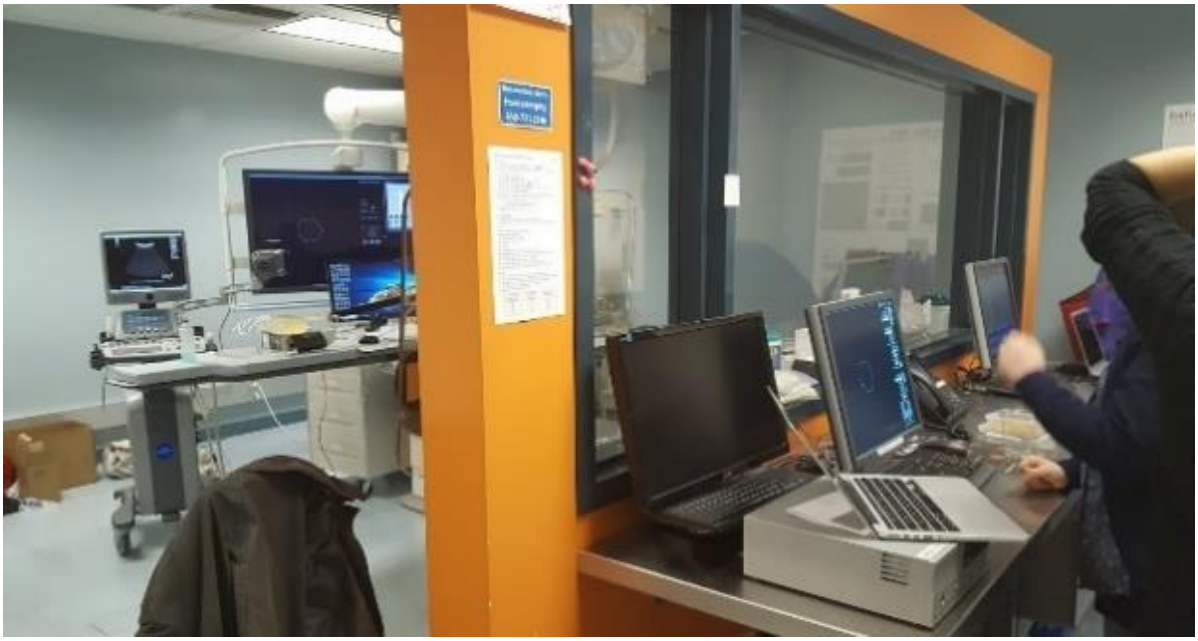


Figure 8. The Zeevo lab, view 3 (Photo by Erin Young)



Figure 9. The Zeevo lab, view 4, the workbench (Photo by Erin Young)

The Zeevo lab's website mentions that, 'we have investigated a wide range of basic engineering, physics and pre-clinical questions… Translation of technology developments from the lab to the clinic is the goal.' Despite this description of the space as a place for

technological development across disciplines, the lab is situated in the basement of the hospital at University X, a traditionally clinical, medical space. Similarly, the C-arm CT scanner is conventionally a medical object – a black-boxed technology which is used in clinical settings, for clinical purposes – and is described as '… a world-class piece of equipment that is capable of producing the most advanced forms of fluoroscopic and CT imaging for anatomical, functional, quantitative, brain, cardiovascular and body applications'. It is necessary to explore what happens when the steerable needle and its robotic platform (as can be seen towards the centre-right of figures 6 and 7) from the engineering space, the Robotics lab, are brought into this clinical space, alongside its clinical objects.

4.4.2 (Interessing and) enrolling the lab technicians: phantom and ex-vivo testing begins

Selena, a biomedical engineer, is the temporary manager of the Zeevo lab. Whilst she has previously been interessed, the enrolment of the lab brings with it her enrolment, as well as a coordination of actors around testing the steerable needle platform in both phantom tissue as well as in ex-vivo liver. These tests take place in the Zeevo lab: figure 10, below, shows the steerable needle inserted into ex-vivo liver; figures 11 and 12 show Jennifer as she ultrasounds the liver to locate the needle tip and the 'target' (a small piece of fibre inserted to mimic a tumour); and figure 13 shows one of the CT scans, administered by Selena, on a computer screen, displaying the needle tip and the target inside the ex-vivo liver. Figures 14 and 15 demonstrate similar tests on the same day, using phantom tissue as the medium through which to move the needle towards the 'target'. These tests are framed as 'calibration' experiments in preparation for in-vivo testing – that is, to try and ensure the experiments on the pig cadaver and live pig will 'run smoothly', as per the fourth research aim in the project proposal. Selena's contribution as a lab technician was required to for these tests to happen, as Jennifer explained to me:

"A big part of the collaboration is with [the lab technicians] because we are working together to [develop] the tests, and it's done a few weeks before. We go [to the lab] and try to discuss the best setup, the best setting for the machine, these sort of things… I didn't know how to process the images I was getting after the test, and [Selena] helped me processing the images [and] the data…" (Jennifer)

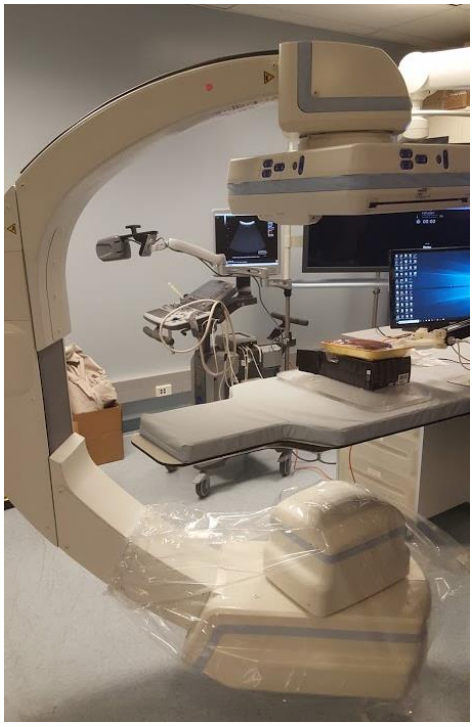


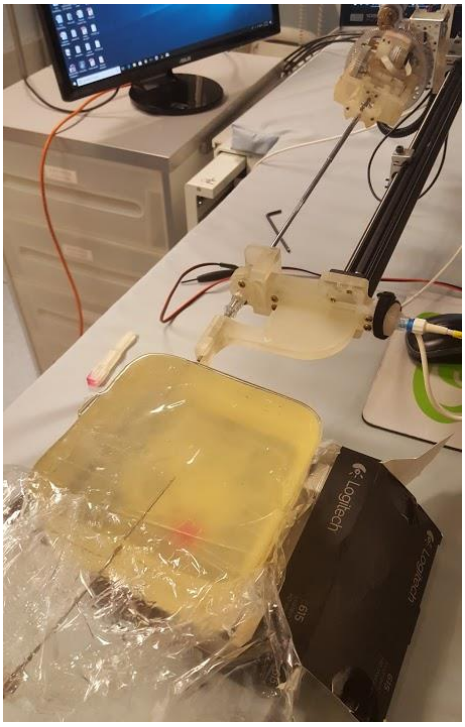


Figures 10 - 12. Ultrasound imaging the needle in liver ex-vivo (Photos by Erin Young)



Figure 13. CT scan image of the needle in ex-vivo liver (Photo by Erin Young)





Figures 14 and 15. The needle in phantom tissue/agar jelly in the Zeevo lab (Photos by Erin Young)

Selena and Jennifer settle on the extent of Selena's input into the Medical Robotics project: 'She's going to be part of the [next] paper, but actually she's not really interested in what's going on. It's more [that she's involved] because she's running the system that tells us if we are right or not' (Jennifer). Selena elaborated:

> "I don't feel like I'm working on [the project] – I'm just a support!.. I am a really temporary person [at the lab]… They just keep the lab live. But the actual competencies that somebody [needs to] run the lab, I don't have… Because this is a lab for interventional radiology - my background is the muscular skeletal system – that has nothing to do with interventional radiology; [maybe just] image processing… I mean, it's not that I have no clue of what I'm doing, because I've used images from the scanner before, but I'm not coming up with new experiments there. It's not that I dislike it but it's not my main research… I don't have a big impact." (Selena)

Once again it is necessary to attend to the interview data here as a source of insight into the lived experiences of the human researchers, since "Latour (1999: 20) has emphasised that in talking with human participants, the focus is upon understanding what things and people do, not what they mean: 'actors know what they do and we have to learn from them not only what they do, but how and why they do it'." (Fenwick and Edwards, 2010: 151). As exemplified through the relationship between Jennifer and Selena around the act of image processing, the project participants attend to ideas concerning 'engagement' in the project in a somewhat quantifiable sense, often rooting their discussions in a subconscious commitment to notions of 'input vs presence' or 'doing vs advising'. These in turn manifest in undercurrents of recognition regarding oneself and others as being either central or periphery to the project. This typically anchors around an individual's relationship with Jennifer - as well as with the project's experimental design - and to what extent they support, help, aid, guide, advise or assist her, either closely as an 'active collaborator', or loosely as a 'service provider':

> "You can consider me as a service provider, not directly involved specifically in the design of the experiment… every time they do a major change to the instrument, we do first a very… basic, like, try on a pig liver ex-vivo - she buys it at the butcher, and we see if the whole setup works… They come in and they do their magic - and we basically help them at making sure they get the right images…" (Selena)

> "Basically we are support - we are not really into the design of the experiment, but we help them quite a lot in obtaining the best possible images… they have no clue of what a good image is! For example, we tell them, 'oh we can achieve a better contrast, let us work on the parameters of the machine' – or like, 'if you image it from this other angle then it's going to be better'. So we provide the quality of the image that means for them better information [and] better data… But the design, not really." (Selena)

Ideas around degrees of involvement, engagement, contribution, and even investment, in the Medical Robotics project – based upon who does and does not make the decisions - leads to what I term a 'multiple perceived isolation'. This is a general 'us vs them', 'they vs me', or 'I vs we' mentality across the researchers which comes through in the way they describe their lived experiences of working on the project, and which contributes to the overall 'messiness' of the project's interdisciplinarity.

During these 'pre-tests', as the 'engineering' needle makes its way into the 'clinical' space of the Zeevo lab, drawing together heterogeneous elements from inside and outside of the lab, actors enrol and coalesce, and ontologies entangle. Interdisciplinarity is not only enacted here through entanglements between 'human spokespersons' for engineering and medicine, but also through previously envisioned alliances, from the interdisciplinary project proposal, coming to fruition between human and non-human assemblages; that is, between Jennifer and Robotics lab actors, including the steerable needle, and Selena and Zeevo lab actors. For Jennifer, the needle is something to be tested; for Selena, the needle is something to be imaged. These are different, yet related, ideas, that can be described as overlapping ontologies. Yet despite this – or maybe, rather, due to this - ontologies-in-the-making are coordinated during enrolment, as disciplinary spaces and objects draw together at the site of the 'Zeevo experiments'. The experiments represent a site of, and a physically bounded space for, interdisciplinary and ontological negotiations and entanglements.

4.4.3 The steerable needle, and other actors, resist

The initial experiments which I observed were conceived as a day of 'troubleshooting' on a pig cadaver, before the 'real tests' on a live pig. Mina, one of the interventional radiologists, told me that, 'Jennifer needed my guidance I guess in terms of where to stick [the needle] and finding good trajectories that were safe within the cadaveric pig to plan for the live pig'. I had been informed that Mina would indeed be in attendance, but that Pete, the other doctor, would be only joining for the live pig experiments due to prior

commitments. Nevertheless, Pete's entanglement with this experiment, despite his physical absence, was at the forefront of mind:

> "I cannot go on organising the tests on the animal without asking or without showing my results to our clinicians… they are doctors so their schedule is crazy, but if I'm summarising my problem, [we can] facetime and talk about issues. Sometimes it's more about I'm asking Pete directions, for example, if there's a certain part I want to test with the needle which I'm not really sure is in a feasible area of anatomy. And they are really helpful - of course I can type on the internet whatever anatomy I want - but they will say, you cannot really go from this side to insert the needle, or be careful because we are going to use a pig and maybe it's the most similar animal inside to humans, but of course it's going to be very different, for example, the position of the ribs with respect to the usual access issues in a human. So they have these little things, that if you want to make a test that really works, then you need them… [With the surgeons] more for practical reasons, we don't work every day. Now I am working on very technical stuff… if we are really close to the test [or an article submission] then maybe [we talk] weekly… Otherwise, it's maybe once every two months, maybe less' (Jennifer)

I was mindful of this cognisant 'necessity' for the radiologists' involvement in the experiments, as previously described to me by Jennifer – and an alliance set out during problematisation and interessement - as I joined the experiments this day. As I entered the Zeevo lab, Jennifer introduced me to Angelo, an engineer who previously worked with her at a different institution, and who had travelled from Italy to help her with these experiments. Throughout the morning, Jennifer and Angelo worked on some calibration issues with the needle, while Mina questioned them about the degree to which the needles can steer. Jennifer and Angelo continued to 'tweak' the needle throughout the day, often with Mina having stepped away from the pig, observing from afar. Once Jennifer signalled that they had completed one particular round of calibration, Mina proceeded to

ultrasound the needle inside the cadaver's liver (as shown in figure 16). She explained to Jennifer and Angelo that some gas was obscuring the ultrasound image on the screen: 'That's why we do this. It's better to make mistakes on a dead pig not a live pig. But the problem is… the bacteria in the gut [causes] gas'. Despite this apparent move towards a mutual resistance to enrolment (and to each other) between the needle and the gas, Jennifer's interview suggested that the ultrasound does not (yet) resist enrolment, as it collaborates with the radiologist:

> "When the needle is going to the target, then it's all a matter of holding the ultrasound…. That's the doctor, and I'm doing some offline things because we have to verify that our assumptions are right or if the needle is behaving differently… So essentially it would all be done by the surgeon, because you go over the place where the needle is supposed to be with the ultrasound, and with the other hand click on the image. We are actually relying on the surgeon telling us where the needle is - we're not doing an automatic detection on the ultrasound. We have a radiologist which is way better!" (Jennifer)



Figure 16. Mina, the interventional radiologist, ultrasounds the pig cadaver, as the engineers watch (Photo by Erin Young)

Mina suggested that they take a CT scan to verify what they have seen on the ultrasound, and Jennifer agreed. Haruto, another lab technician, like Selena, but from the industry-side, has taken over the C-arm supervisory role for the day. He ensured that everyone was behind the glass screen in the lab, to protect from X-ray radiation, and proceeded to take the CT scan using the computer controls. Mina studied the resulting 3D image, manipulating it with the mouse, and commenting that, '…in the first step it's curving like it should be, but it's difficult to see if it goes in the right direction after that. It looks like it's going in the opposite direction… when you look from the front it's moving to the right instead of to the left'. Haruto suggested the issue might be that the scanned image has flipped on the screen, but Mina said this is not the case; the tissue is resisting the needle, and the needle is resisting the tissue.

Indeed, Sophie, a PhD student previously on the project had similarly told me how tissue resisted the needle in her work, explaining that: 'The problem I was facing was that the opening at the top of the needle gets filled with tissue as you're inserting it into the liver, and so when you then try to deliver fluid through the needle to the ablation site, you have incredible pressure build-up because you have tissue stuffing the end of the needle. So, I was trying to figure out ways to still allow fluid to flow through, [whilst] struggling with the high pressures and the thin tube'. Similarly, Jennifer had also told me that, with reference to her earlier work in the Robotics lab, 'the needle is very flexible but it has its own constraints – it cannot all of a sudden turn around. There is a radius of curvature… you call it the kinematic of the needle - how it's built - it can do certain movements but not every movement'.

Back in the Zeevo lab, Mina pointed to the screen and traced her finger between the scanned image of needle and the target. 'It's hard to measure two points in space!', she told me. 'Do you think if we push the target in deeper it would be more reachable?', she asked Jennifer. Jennifer thought this might help in a future test, but this particular day of experimentation and 'troubleshooting' technological issues had come to an end.

During the day I had observed as the multiple human actors, whilst enrolling into their 'assigned' *roles* within the somewhat cyclical nature of the 'pre-test' validations (figure 17), nevertheless continuously negotiated their *practices*. Whilst Jennifer had previously expressed a level of dependency on the radiologists for experimentation, they nevertheless entangled and dis-entangled in various ways, around the steerable needle, suggesting that their 'necessity' came only at certain, and perhaps more discrete, moments in the process.

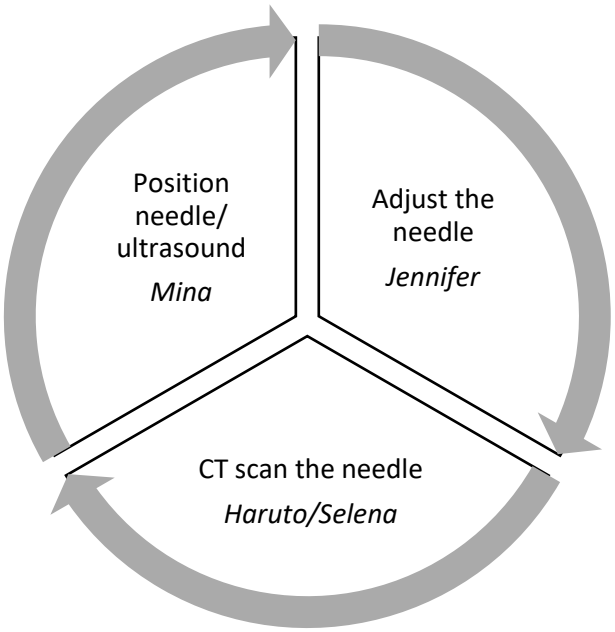


Figure 17. The cyclical pre-test process with human actors (clinician-engineer feedback loop)

There is 'activated' agency and resulting resistances of various technologies and other non-human components within the experimental setup – including the steerable needle. Not only does the needle mediate the actors' ontological negotiations through its resistances, but it negotiates with and alongside them. Through this mediation, and the other actors' resistances, the radiologist, the engineers' and the lab technicians' interdisciplinary practices are enacted. Somewhat counter-intuitively, through the resistance of the needle's path, as well its resistance to being visualised via ultrasound, the needle enrols allies during these experiments. It is particularly interesting that the 'roadblocks' throughout the day, and indeed since the start of my time in the field –

including the difficulty of enrolment for the two central technological developments - encourage a 'ramping' in interactions; that is, greater (bursts of) communication and increased touchpoints between multiple actors, both human and non-human. To give one example, the needle-engineer-robot-software hybrid is drawn closer towards the evolving radiologist-ultrasound-computer-pig-CT hybrid in a re-configured alliance. The needle is both an object *of* and *for* interdisciplinary coordination, and this status will continue into the final Zeevo experiment I observed.

4.4.4 The 'Zeevo' experiments conclude: a site for interdisciplinary coordination work

My narrative breaks down this day of the experiments on the live pig into three (interdisciplinary) 'moments', both for ease of explanation, as well as to illustrate, moment-to-moment, the changing entanglements and reconfigurations of, and tensions between, the actors during enrolment. Firstly, I present multilateral trials of strength, emerging from a multiplicity of ontologies (and constitutions of success and failure) as interdisciplinary enactments. Next, the narrative focusses on the ontological politics between a radiologist and an engineer, and how their competing realities-in-the-making temporarily hung together, in another enactment of interdisciplinarity. Lastly, I'll discuss what I term the 'politics of purpose' in this unfolding interdisciplinary project (which can be seen as a 'seed' for different forms of mobilisation), and where the multiplicity of the needle sits within this.

Moment 1: multilateral trials of strength between the needle assemblage, the researchers, and the ultrasound visualisations

'The goal today [is] to translate the work that they'd been doing in phantoms and in cadavers, to an in vivo live animal model', Pete told me. So, with the pig breathing as a new variant, and with a veterinarian now present, the testing began. Throughout the morning, as during the 'pre-tests' on the ex-vivo liver, there were still issues visualising needle curvature in the tissue with the ultrasound. As Pete ultrasounded the pig (see

figures 18 and 19), the team huddled around the screen trying to locate the needle tip, to no avail; Pete suggested a new access site might remedy the issue. Angelo, on the other hand, suggested using a new needle or target. Rather than symptoms of their disciplinary training and foci, respectively, these are materialisations of divergent research practices. The difference between the engineer's and the radiologist's conclusions is grounded in the different ways in which they accomplish the needle and its experimentation. 'The target is not the problem,' said Pete to Jennifer, 'the gas in front of it is [the issue]'. Mina agreed that the gas prevented visualisation, as it did in the previous cadaver experiment. 'The problem is if we change the insertion site as well as the needle, then we've changed two variables', said Pete in reaction to Angelo's suggestion. Markedly, Pete added, 'Our jobs [as surgeons] are secured for another day!', quintessentially exemplifying the nature of enrolment within this case.



Figure 18. Pete ultrasounds the needle inside the in-vivo liver, while the engineers look on (Photo by Erin Young)



Figure 19. Some of the team inspect the ultrasounds (Photo by Erin Young)

The multilateral resistances, and (resulting) negotiations, between the pig's anatomy and the needle, as well as the engineer Angelo's and the radiologist Pete's suggestions, all of which are brought into focus around the act of ultra-sounding, illustrate how trials of strength mediate the actor's enrolments during the experiments. These complex, multi-way relationships mark the multiple realities, and at times competing interdisciplinarities-in-the-making, not only of the engineers and the radiologists, but of the non-human actors, including the emerging technologies, too.

Talking to me afterwards, Jennifer and Angelo, the engineers, consider this part of the experiment a 'failure'. For them, the needle technology did not improve in accuracy, nor did the needle fully enrol the ultrasound machine, despite the goal to '…get an ultrasound image and find the needle in it', as expressed by the PI Andrea. Pete and Mina, the radiologists, on the other hand, assure me that they expected this to be the result, and are accustomed to these kinds of 'bumps' in their profession; it's 'all part of the process', they tell me:

> "I know it's a very controlled environment that the engineering group has worked in, where they have these gelatine or agar phantoms, and everything was working perfectly. And then it was really disconcerting for them to then go into a liver and see things fail. I guess I'm used to seeing that kind of failure in liver; that's why we were doing it in liver, because we knew there were going to be blood vessels and you're not going to be able to find a perfect path. You just have to figure out how to make this work in the imperfect setting of all these blood vessels in the way, and gasification that's going to prevent imaging. I mean, hopefully the level of frustration they felt is normal - for me and Pete it's like, yes this happens, this is what we see all the time when we're in procedures. Biology trumps all, and hopefully we can help them from that perspective, and that just means that we'll have to find ways of engineering around reality." (Mina)

The ultrasound imaging, or lack thereof, is enacted differently by different actors; noticeably, the clinicians and the engineers. Likewise, enactments of success and failure, particularly in relation to the needle, are different for the clinicians and the engineers; 'in-the-making', these conceptions vie temporarily to be privileged. Again, rather than viewing these multilateral trials of strength as 'direct results' of the researchers' disciplinary trainings, backgrounds or experiences, I instead bear witness to them as disciplinarities and interdisciplinarities in construction and in practice. Successes and failures were negotiated and constructed, as 'plans run into local resistance, which is dealt with locally. Materials do not behave as they are supposed to, equipment does not function smoothly, and it is difficult to configure everything so that it resembles the plan. The laboratory contains idiosyncrasies that become central to day-today research' (Sismondo, 2010: 159). The engineer, Angelo, enacted the issue and potential solution in one way; the radiologist, Pete, in another; the lab equipment in another, and so on. Alliances and discords were built with the needle when subjected to trials of strength (Sismondo, 2010), and ontologies-in-the-making vie for realisation. The enactments of these interdisciplinary entanglements continue to (re)configure during the lab

experiments through the next moment of enrolment, as multilateral trials of strength from a multiplicity of ontologies emerge.

Moment 2: ontological politics between a radiologist and an engineer, or productive tensions

As per Pete's suggestion, a new access site on the pig is tested. 'I certainly have no problem and feel it's best to chime in when I see opportunities to explain things that somebody from a technical standpoint might not appreciate about the translatability of a technology or project based upon what I'm seeing… I'm definitely intimately involved during the project, so it's not just consulting and advising - I'm actually doing the ultrasound, I'm doing the imaging, I'm looking at a good spot to put the needle, I'm looking at a good spot to put the target needle and physically doing that.' (Pete). Once the robot has driven the steerable needle towards the target, from the new insertion point, a CT scan is taken (see figure 20). But an issue has arisen – the needle is still missing the target. It is only at this point, then, that Jennifer decides to go ahead with Angelo's original suggestion to test a new needle. While Pete and Mina chat together away from the pig, Jennifer and Angelo insert the new needle. It misses the target inside the liver again, to Jennifer's disappointment, but upon her request, they ablate some tissue anyway.



Figure 20. Haruto takes a CT scan, while Pete and Jennifer wear lead vests which allow them to stand on the same side of the glass as the C-arm and supervise (Photo by Erin Young)

The act of measurement is the act of enactment, argues Mol (2010). As the team continue their experiments, measuring the distance between the steerable target and the target needle, thus the needles, the team, and other actors involved, including interdisciplinarity, are enacted. 'An experimental result occurs in a specific time and place… Experimental knowledge is not knowledge directly about an independent reality, but about a reality apparently constructed by experimenters (Knorr-Cetina, 1999)' (Sismondo, 2010: 159 - 160). Pete's and Angelo's different and competing realities-in-the-making are contested and enacted through the experiment, through the consecutive realisation, and displacement, of *both* their suggestions at different times; both had the potential to exist, and did so at different times. Trials of strength between the gas, the ultrasound and the needle negotiate Angelo's and Pete's ontologies. 'Ontologies are brought into being, sustained, or allowed to wither away in common, day-to-day, sociomaterial practices', explains Mol (2002: 6). The different versions of the needle through which the engineer and the radiologist generate different knowledges about the experimental 'issues' involve

different collections of skills and procedures. Nevertheless, Angelo's and Pete's approaches, and thus these particular realities, withered away once enacted through experimentation, and were not fully enrolled into the network. This episode illustrates coordination work between competing realities-in-the-making as they temporarily hang together during enrolment, and how ontological politics were mediated by the multiplicity of the needle and the needle assemblage.

Moment 3: politics of purpose

As I sat behind the glass in the lab with Mina and the vet, waiting as the needle was directed to ablate in the liver, Mina explained to us that 'radiofrequency in a needle like this would not kill a tumour, it's just an interesting concept… This is very pie in the sky research. The concept they're really exploring is using a steerable needle to get from point A to B, but right now it's not getting where it needs to be. It works really well in gelatine, in a phantom though'. Indeed, during my interview with her, Mina added that, "I have [always] viewed this project more as a proof of concept. In terms of it's actual 'practicalness' of delivering a curved needle to a location so that you can ablate, I feel like that's very impractical… [but] I think just having the proof of concept of being able to steer a needle through human tissue, and get it where you want it to go quickly and reliably and through a non-linear path has value." Jennifer, on the other hand, wants to apply this work directly to the market,[63] and thinks the robotic needle assemblage ought to be usable in surgery: '…we want to do tests that can really do something for real, not just complex models. There's a lot of obstacle avoidance in research, tonnes of papers - but then there is no prototype that really goes there, in a medical application' (Jennifer). In this way, as the needle enrols allies into the network, different (potential, interdisciplinary) realities hang together around it, according to its multiplicity. 'Politics of purpose' are in construction

[63] Traditionally, this might be considered as an interdisciplinary 'mis-communication'.

with the multiple 'realities-in-the-making', multiple needles, and therefore multiple potentially very different points of translation.[64]

4.4.5 The multiplicity of the needle

The multiplicity of the needle has in great part allowed me to become attuned to the multiple ontologies-in-the-making, and it is this multiplicity of the needle to which I now directly attend. 'Attending to enactment rather than knowledge has an important effect: what we think of as a single object may appear to be more than one.' (Mol, 2002: preface). As we have seen, the enrolment of the Zeevo lab and its affiliates brought with it the steerable needle enacting different configurations of interdisciplinary practices among those actors it encountered. Like the HAT in vu Henry's (2018) study, with each association, the needle has acquired new, often overlapping roles corresponding to different sets of disciplinary and interdisciplinary practices. In its early life as an object of robotics research, the needle participated as a 'theoretical playground'. Once the needle was enlisted by Andrea and Mina as a device of interessement, it began to participate and function as an engineering design task as well as a potential job aid. Now during enrolment, the relation of the needle to various actors has evolved again; it is what it was previously, as well as now performing the roles of a surgical tool, part of a robotic assemblage, 'something to be tested' and 'something to be imaged'. What Mol (2002: 6) describes as 'multiple', and 'more than one but less than many' (Mol, 2002: 55), this multiplicity has created different configurations of interdisciplinary practices involving different accountabilities and interests for the actors, co-existing and hanging together at once – even as it was installed as a device of interessement to draw those enlisted actors closer to the problematisation. The needle plays a central part in the coordination of engineer's and the radiologists' activities. Furthermore, alongside this ontological multiplicity, there are physically multiple different needles, built by Jennifer, for any that

[64] Whilst Mina's position as a focal actor would at first appear to have primacy, Jennifer's 'privileged' status as a co-device of interessement affords her and her co-devices power in the network.

may break during the experiments (though some of these needle prototypes do not enrol in the network). In this way, the interdisciplinary project actors, both human and non-human, are now confronted with competing demands corresponding to different sets of practices. This multiplicity generated trials of strength, negotiations and resistances during enrolment, and the coordination work during this period was in turn mediated by this multiplicity. It created controversies over the identity of the needle (Akrich, Callon, and Latour, 2002); controversies which I have described as ontological politics (Mol, 2002). Towards the end of enrolment, the work of the interdisciplinary project 'team' is to determine how to mediate these competing versions, thereby 'attuning everything to everything else, one way or another' (Mol, 2010: 1757). Actors were enrolled, and alliances have been built. The multiplicity of ontologies was negotiated and repeatedly reconfigured with interdisciplinary enactments. But 'no network is immutable' (Fenwick and Edwards, 2010: 11):

> "…not all entities are equally enrolled. Some cooperate for a while and then drop out while others become fully integrated into the network. The stability of a network, therefore, depends on… translation. This is when entities enrolled into a network change their identities, redraw their boundaries and modify their practices to align more with that of the network." (Wong, 2016: 107)

4.5 (Partial) Mobilisation

To recap, the narrative has followed the steerable needle through its interactions with other actors in the Medical Robotics project network, describing how it 'enacts an array of interrelations between disciplines, with distinctive effects' (Barry and Born, 2013: 13). I began this findings chapter by describing how Andrea and Mina defined a problematisation that established the moving boundaries of the Medical Robotics project during the first moment of translation. The instalment of the needle as a device of interessement delegated certain identities to the various actors interessed, including the radiologist, the engineers, and the technologies collaborating in the design and

prototyping of the robot. During enrolment, the multiplicity of the needle participated in creating (interdisciplinary) trials of strength that were mediated by fluid processes of jostling, negotiating multilateral resistances and beginning to coordinate multiple ontologies-in-the-making through the Zeevo experiments. Entanglements and shifting relations, emergent and shifting boundaries of the project, and disciplinarities and interdisciplinarities continue to be constructed during the fourth moment of translation (mobilisation), and entities are produced and performed through these relations - physical, conceptual and otherwise.

My narrative thus moves to describe how interdisciplinary coordination work already performed is extended and partially-mobilised as translation happens. A translation 'is an act of invention that operates by joining previously disparate elements' (Lezaun, 2017: 4), and mobilisation is 'when the network becomes sufficiently durable that its translations are extended to other locations and domains' (Fenwick and Edwards, 2010: 10 – 14). My narrative has not focussed on tracking a 'finished' technological outcome, but rather the processes around building the technology, and how the different ontologies-in-the-making come together around this. "In Law's words, we can say that building a technology is about 'how to juxtapose and relate heterogeneous elements together such that they stay in place and are not dissociated by other actors in the environment in the course of the inevitable struggles – whether these are social or physical or mix of the two' (Law 1989, p. 117)" (Sørensen, 2009: 52). It must therefore be noted once again that although this narrative, for the purpose of the D.Phil, appears 'finished', it is in fact '…continuous and unfinished, precarious, and partial… a heterogeneous emergent phenomenon', just like the technology, practices and interdisciplinarities being enacted by the Medical Robotics research team (Hassard and Alcadipani, 2010).

My narrative will now explore what prevails in enactments of technologically-mediated interdisciplinarity during this final stage of translation in the Medical Robotics project; and where, if at all, the network has become durable enough to extend to other domains. I

will describe how through processes of translation, coordinating differently enacted realities in different ways, certain ontologies were 'realised', whilst others were displaced (Law and Mol, 2002):

> "Which reality-in-the-making is allowed to continue to exist becomes a political question. For a short while, the… realities- in-the-making were allowed to co-exist, but [there are] pressures by the collaborative project with a shared purpose [to start] translating the findings… This allowed for both produced 'realities' a chance to be taken into account and carry on breathing further, for the time being. Hence, the choice of research methods and approaches for any research project is not an innocent decision, but becomes a choice laden with political consequence – whose reality is it that is allowed to exist?" (Rimpiläinen, 2015: 148)

4.5.1 Coordinating the needle to (un)settle differences

Mediating competing realities-and-interdisciplinarities-in-the-making, the different needles hold together (Law and Mol, 2002). Multiple actors engaged in the work of coordination so that the multiple ontologies of needle 'hung together' in such a way that they have become so close, or bracketed, that they might *appear* to be stabilised enough to extend to 'other domains' through immutable mobiles (Mol, 2002).[65] For example, I recall an earlier portion of this chapter's narrative when Jennifer recounted Pete's concerns around the needle's ablation. In a later interview, but prior to the Zeevo experiments, she concluded the story:

> "[Pete] called me to [change his stance and] say that the most essential part that we want to demonstrate is that [the needle is] arriving precisely in one point. In the end we just agreed, we will insert this target, and then we go there precisely, we

[65] "An immutable mobile, says Latour, is something that moves around but also holds its shape. Indeed, in this way of thinking, it holds it shape in two importantly different ways. On the one hand, it does so in physical or geographical space. On the other, it holds its shape in some relational and possibly functional manner where it may, to say it quickly, be imagined as a more or less stable network of associations" (Law and Singleton, 2005: 335).

> burn, and then the objective will be taking a picture of your target which is burned exactly where it was…" (Jennifer)

Pete's original attitude to ablation – that there are more advanced ways to perform the procedure on a patient in practice - is displaced when he explains his change in thought, that the needle's purpose in the project is not to ablate, but rather to establish the 'best' path through the tissue to the point in the liver which needs to be ablated. Jennifer's enactment of the needle, its 'reality-in-the-making' as 'something to be tested' in an *engineering* design task, is privileged through this interdisciplinary coordination work – and it is something to which Pete comes to subscribe. What is key, however, is that they are both essential in order for the mobilisation to happen in this way.

Indeed, interdisciplinary socio-material entanglements are (re)configured again and again around the multiplicity of the needle. Jennifer and Joseph explained to me:

> "Sometimes you want to see if the technology you are developing, if it's really helping the surgeon. Because sometimes you do a lot of work and then the surgeon says, 'I don't need it'. That's why we want to demonstrate that needle steering is really going to be something useful; we have to steer a lot, otherwise the surgeon will tell you, 'okay nice device, very complex, but I don't need it'…[You must] make them appreciate that you are doing something that they cannot do otherwise… There is this dual relationship between engineers and doctors. Sometimes it happens that doctors ask more than is really doable… And then on the other end, sometimes, engineers can come up with a very complex solution to a really simple problem." (Jennifer)

> "I really feel like working with clinicians and ruthlessly pragmatic people, and trying to strip your thing down to its most basic elements, has been something I've learned by working with these people. And what that means is, don't try to dress your thing up with more complexity than it needs to have, make sure that your thing is fundamentally useful… You realise when you go into the operating room or

> talking with surgeons, they don't care about how cool your needle is. It was a re-adjustment of priorities… the only thing that matters is it working, and working well, and just let the methods follow from there." (Joseph)

Here I re-visit 'politics of purpose', where Joseph and Jennifer explain interdisciplinary coordination work as a stabilisation of the needle's purpose. As has been recurrent, Jennifer describes two 'disciplinary' groups – the engineers and the doctors, inter-disciplines themselves. Could these comments suggest a conscious, or sub-conscious, 'need' to settle an ontological, interdisciplinary 'ground truth'? In order to coordinate the various ontologies around the needle, the actor-network coordinated the varied enactments of the needle, privileging the needle as an engineering design task – albeit for the use of the radiologists, whose enactments of the needle meet in the engineers' 'in the middle' somewhere. This 'hierarchy' of ontologies was established based on the OPP*, but* ontologies do not exist in isolation; "… as Donna Haraway would say, they *interfere* with one another and reveal what Marilyn Strathern would call *partial connections*" (Law and Mol, 2002: 10). Interdisciplinary, socio-material politics circulate through the needle as it coordinates ontologies during mobilisation. Joseph, an engineer, and Pete, a radiologist, told me about seemingly competing 'realities' in their respective interviews:

> "…a mechanical engineer partnering with a radiologist, you know, this is not the first nor the last time that this is going to happen. But if you just go down to the animal lab, could me and my immediate colleagues pull that off? No way! Trying to assemble and understand the robot, we'd fail at the start. And the same thing, watching the engineering postdocs and students trying to figure out how to work with a live animal. So I think that is to me the essence of interdisciplinary work, which is essentially nobody on their own could pull this off, but when you bring all of your skills together, there's going to be varying degrees of overlap that you can actually make it work." (Pete)

> "All this comes down to is less about knowledge, and more about motivations. I feel like everyone's capable of filling everyone's shoes. Of course there's tonnes of background that we don't share, but I feel like each person, we can all pick it up at this level, it's just that we have different motivations." (Joseph)

While Pete expressed that the research team were only capable of achieving their research aims through the engineering-surgery collaborations, Joseph, on the other hand, saw it as a 'bonus' rather than a necessity. Definitions of interdisciplinarity were multiple even in this way during the lived experiences of the researchers.

4.5.2 An inscription of a translation

Lastly, and importantly, I re-visit the potential mobilisation of the twofold technology which was laid out in the project proposal, at the point of problematisation; that is, the development of the needle technology, as well as the development of an imaging technology, ultrasound, to monitor this. The research proposal aims written by Andrea and Mina specified the 'successful' optimisation of ultrasound-based localisation of curved needles, alongside validation of the ultrasound-guided needle steering system. But as I have shown, CT imaging was mobilised 'instead of' ultrasound imaging, suggesting a privileging of the engineers' 'failure' reality; they deemed the experiments a failure because ultrasound did not fully enrol. This 'failure' to satisfy the research aims means a lack of 'full' mobilisation; a lack of *one* mobilisation. Indeed, objects can represent configurations and ongoing tensions, extending them to other domains, and the 'mobilised' CT images produced represent some such of these objects. Whereas the ultrasound began to 'fall out' of the network as Joseph - who had originally enrolled in an adjacent network when the project 'had some ultrasound image processing problems [so he began] doing image processing for ultrasound because that meshed with [his] background in image processing' - unenrolled, CT imaging brought with it a 'more successful' stabilisation. I think that the CT enrolled (in contrast to the ultrasound) due a focus by the project actor-network on needle development, rather than ultrasound

'development'. CT was black-boxed in the network at the point of problematisation, however, and thus found the opportunity to mobilise with the needle as it was 'improved'. The CT scans, emerging artefacts from the network, can thus be conceptualised as inscriptions and immutable mobiles, as a result of a translation.[66] Figures 21 – 24 show the X-rays taken by the C-arm CT scanner during experimentation in the Zeevo lab.



Figure 21. The computer set-up 'behind the glass' in the Zeevo lab (Photo by Erin Young)

[66] My D.Phil thesis itself is an inscription.



Figure 22. CT imaging of the needle (Photo by Erin Young)



Figure 23. CT imaging of the needle, 3D view (Photo by Erin Young)



Figure 24. CT imaging of the needle, 3D view 2 (Photo by Erin Young)

An inscription is the result of a translation of interests into material form (Callon, 1991: 143), and the notion of inscription refers to the way technical artefacts embody patterns of use.[67] (Scientific) knowledge can be embedded in procedures of inscription (Latour, 1987), and in the case of the Medical Robotics project, the CT scans (of the needle moving from point A to point B) are *visual* inscriptions and immutable mobiles. 'Immutable mobiles have the capacity to fix knowledge and allow it to be disseminated far beyond its point of origin', explain Hassard and Alcadipani (2010: 9), and thus these CT scan images may be taken forward and participate in future experiments, or other happenings, organised by the Medical Robotics project. 'Successful' translation produces inscriptions and immutable mobiles,[68] and these CT 'inscriptions' represent embodied interdisciplinary configurations and enactments as they begin to circulate through other networks, including this thesis. 'Photographs, ultrasounds, videos, and other visualisations reinforce some narratives and disempower others' explain Burri and Dumit (2008: 305), and in this

[67] 'In general, any component of the heterogeneous network of skills, practices, artefacts, institutional arrangements, texts and contracts establishing a social order may be the material for inscriptions', explain Monteiro and Hanseth (1996: 330).
[68] 'Contrivances like maps, photos, logbooks and the printing press were considered immutable mobiles', explains Wong (2016: 107).

way these CT visualisations have come to represent one story of what has happened in the Medical Robotics actor-network. Enactments of ultrasound and CT scans, their machines and their assemblages are central to the narrative, and 'different types of interrelations between disciplines… are embodied in [such] interdisciplinary assemblages' (Barry and Born, 2013: 6). Interdisciplinarity is embodied practice here as it has been throughout the four moments of translation; each a contingent, local and situated practice.

4.5.3 Summary, and onto the next cases

This findings chapter has described how an array of humans and non-humans participate in research and technological development in the Medical Robotics project at University X. Following the trajectory of a steerable needle, through four moments of translation (Callon, 1986), I have explored how research aims are tackled in practice when different 'disciplinary' approaches, most notably engineering and medicine, are brought to bear upon them. Situated (inter)disciplinarities have been enacted and privileged during different moments within this case, and steerable needles were critical particularly during enrolment in these accomplishments, appearing to hold together at times through processes of (interdisciplinary) coordination. Furthermore, the Zeevo experiments participated as a site of interdisciplinary negotiation, where multiple ontologies coordinated in different ways.

This narrative of this case has evoked the socio-materiality of interdisciplinary practice, proposing that technologies-in-development may be sites of (interdisciplinary) negotiation. Heterogeneity between actors traditionally in 'the same' disciplinary group has been illustrated, and a 'disciplinary black-boxing' seems to have occurred by actors in relation one another's practices; 'they do their magic', said Selena of the engineers from the Robotics lab. Moreover, non-humans have been shown to participate in interdisciplinary practices, and it can be suggested through this case that the relationship between interdisciplinarity and the generation of technologies and practices may be irreducible to their antecedent parts and disciplinary pre-conditions. There are 'tensions

stemming from the submission of interdisciplinary practices to disciplinary evaluation' (Barry and Born, 2013: 39), as demonstrated in the episode of disagreement between Pete and Jennifer over the ultimate purpose of the needle when publishing an article, as well as through the lack of acknowledgement around the multiplicity of a 'singular' interdisciplinary problem.

But 'the laboratory need not be neatly bounded by four walls, and laboratory studies need not describe only experimental work… every new terrain is also productive for new insights' (Sismondo, 2010: 118). This is where I move to the second and third case studies – or other instances of the network - Digital Humanities and Energy, where the narrative continues to follow actors through the 'complex nexus of circumstances bearing on the growth and demise of heterogeneous interdisciplinary assemblages' (Barry and Born, 2013: 41).

CHAPTER 5: DIGITAL HUMANITIES FINDINGS (CASE STUDY 2)

5.1 Introduction

This findings chapter explores the second case study in this thesis, describing how a different array of humans and non-humans participate in research and technological development in another 'interdisciplinary' project at University X. The Digital Humanities project (2017 – 2018) builds upon an existing initiative which produced a suite of data visualisation and cartographic tools for exploring humanities data.[69] Some members of the Digital Humanities project team had previously worked on this initiative developing the software, 'Tivoli', and this narrative will follow the co-construction of an open-source, prototype research tool, that I refer to as 'Data Biro', which offers new functionalities for Tivoli. 'Connecting linked data sources to filtering and graphing tools, [Data Biro] provides a framework for humanities researchers to access, explore, and manipulate multidimensional historical data', explains the project website. The narrative thus follows the research team, both human and non-human, as they participate in the design of this prototype digital tool for organising and visualising humanities data.

As with the Medical Robotics project narrative, this chapter will track the trajectory of an analytical token through four moments of translation (Callon, 1986), in order to explore how technologically-mediated interdisciplinarity emerges, moment-to-moment, within the case. To provide a depth of understanding of interdisciplinary practice, a concept - the concept of '*encoding a humanities epistemology into a technology*' - is the nature of the token to be followed.[70] This concept is relatively complex, both as it is 'used' within the project, and as conceptualised within my narrative, and thus should be attended to in detail before going any further. As this chapter will describe, there is a 'concerted effort'

[69] 'Digital Humanities is, broadly speaking, the application of computation to the discipline of the humanities… [but] is, and remains, a discipline very much under construction… [It] often requires a team of people with diverse backgrounds' (Berry and Fagerjord, 2017: 8). See Chapter 7 (Discussion) for further discussion of the Digital Humanities as an 'interdisciplinary', emerging field (as well as the project researchers' conceptualisations in the Mobilisation section of this chapter) (and Appendix A).

[70] That is, 'encoding' as positioned by Nicola, within the broader field of the Digital Humanities.

from the very start of the Digital Humanities project to '*be* interdisciplinary', and for the team to work in 'interdisciplinary ways'. Nicola, one of the project researchers, worked to position 'interdisciplinarity' in certain ways from the project's inception;[71] she situates herself 'centrally' within the project, 'bringing together' researchers from different disciplines. She 'uses' the concept of 'encoding a humanities epistemology into a technology' as a tool to bring different disciplinary researchers together; as a way to help the team work through the project tasks and negotiate their practices. In particular, the concept advocates for an understanding of Humanities researchers' 'ways of working' (and how these might be 'integrated' into new software), primarily for the 'benefit' of the technical researchers. Thus, the concept, the token to be followed through the narrative of this chapter, can be understood itself as an interdisciplinary object; that is, as a 'tool' to help foster interdisciplinarity, it is an 'instantiation' of interdisciplinarity. Broadly, it is an 'aspiration' which underpinned the project throughout my time in the field – an ambition to 'build tools where the tools themselves embody the (humanities) research methods' (Nicola). In other words, the embodiment of a workflow, thought process, and even underlying (disciplinary) assumptions, within a digital tool. It is important to note here that, as explained by Drucker (2012: 87), this is an active endeavour to move 'humanistic study from attention to the effects of technology… to a humanistically informed theory of the making of technology'. This is about encoding *into* a technology, that the technological artefact itself has a particular epistemology 'within it', as opposed to how (humanities) practices might be facilitated *by* a technology (*e.g.* Säljö, 2004). The technology is constructed through 'culturally-specific' and situated design practices, occurring at a point in time (Bijker, Hughes and Pinch, 1987). The concept was introduced to me before the bulk of my fieldwork began – in an early scoping interview with two researchers on the project, Nicola and David – but it was not until later in my praxiography that I uncovered

[71] Her positioning reflects many approaches within the Digital Humanities, as presented in other parts of this thesis: 'DH work confronts disciplinary habits of mind' (Gold and Klein, 2016).

this as the token that I would follow, which could elucidate socio-material practices of interdisciplinarity in the project.

It is also important to note here the significance of the diagrams which will be discussed in this chapter. Nicola encourages Historians to draw diagrams on paper, which represent certain problems on which they are working, to show to the technical team members. These diagrams are based on the logic behind the 'concept', in an attempt to illustrate a Humanities 'epistemology'; that is, to try to explain to 'disciplinary outsiders' what the Historians are working on, their methods and how they 'approach' their Humanities work. Crucially, I conceptualise these diagrams *not* as another 'tool' working alongside the 'concept' to bring researchers together and facilitate understanding, but rather, as a *material part* of the concept. The diagrams 'illustrate' Humanities researchers' (disciplinary) ways of working; that is, their 'ways of knowing', their 'epistemologies'. It is hoped that these, or some form of them, in turn, can be 'encoded' into - that is, 'translated' into or 'rendered' by - the Data Biro software-in-development. This is about moving the diagrams from a (material) domain more typically associated with the Humanities (pen and paper), to one more typically associated with Engineering (software). Nicola in particular wanted these diagrams to help the developers and programmers on the Digital Humanities project team to work more effectively with Humanities researchers, and build software which 'successfully' supports the work of Historians - rather than building a technology that they might 'normally' build, without the Historians' 'input': 'we don't want the engineers to just build something that they know, that's familiar to them - it needs to meet [the Historian's] needs' (Nicola).[72] In this way, the diagrams are *also* fluid (inter)disciplinary objects; they are the materiality of interdisciplinarity, and of the interdisciplinary concept token (see figure 25). The malleability, fluidity and emerging multiplicity of the (interdisciplinary) concept, which the narrative will argue emerges from

[72] This is deemed to be necessary because, according to the 'general' understanding which underlies *this* Digital Humanities project (and many other viewpoints), Historians and other researchers in the Humanities conduct research, and understand data, differently to technologists and scientists. This does not, however, directly represent my arguments and theoretical framing within this thesis.

the ‘dual aims’ of the problematisation, means that it ‘looks’ different, and is practised differently, at different times during the project.

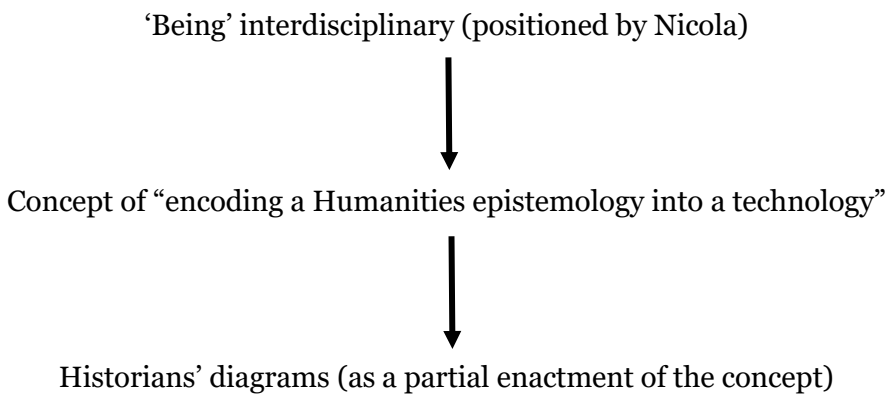


Figure 25. The moving materiality of interdisciplinarity in the project actor-network

By tracing how the (interdisciplinary) concept of ‘encoding an epistemology’ (and its diagrammatic counterparts) ‘gathers’ enrolments of actors as allies into one particular project actor-network, I aim to ‘open up’ the unfolding practices of interdisciplinarity, bringing to the fore entanglements around the development of a technology. First, I frame how problematisation came about through a successful grant extension, before I joined the project. I also introduce Nicola’s interdisciplinary ambitions, and promotion of thought and dialogue around disciplinary and interdisciplinary working practices, during this first moment of translation. Next, I explore the second moment of translation, interessement, as actors are drawn towards the framing of this Digital Humanities project and its goals. The concept of ‘encoding an epistemology’ is introduced into the actor-network as an (interdisciplinary) device of interessement (alongside diagrams as partial material enactments of this concept), and as the token to be followed through the narrative. During the penultimate moment of translation, enrolment, my narrative primarily will focus on two multi-day design workshops, during which time otherwise ‘geographically dispersed assemblages’ are gathered together (Barry and Born, 2013: 3). This is about the emerging multiplicity, and tensions between, the concept(s) of ‘encoding an epistemology’, and the extent to which this participates in consolidating, or not, the (interdisciplinary) alliances that were initially envisioned by Nicola. I will describe how

Nicola's reality-in-the-making jostles to become realised in enactments of interdisciplinarity, displacing other ontologies in the process. Finally, the narrative of the last moment of translation will present the 'theoretical' (rather than 'practical') mobilisation of the (interdisciplinary) concept, to a certain extent, with the human participants mobilising interdisciplinarity differently. Ultimately, a 'vision' or 'version' of (Nicola's) interdisciplinarity was actively engaged (both through discussion and design practice). Yet, while there was some coalescing around the theoretical 'vision', this displaced other ontologies (and *their* 'versions' of 'success' for the project) and was not fully 'realised' in technological design and output. In other words, the concept was inscribed, *not* (fully) into the technology, but in some (thought) practices. Actors 'bought into' the aspirations behind the concept, with some theoretical understanding, but there was a resistance to its 'practical', technological mobilisation. In parallel with this, interdisciplinarity was performed and mobilised in different ways by different project actors. Project researchers 'understood' and practiced interdisciplinarity (and indeed, the broader field of the 'Digital Humanities') in multiple ways (in large part, according to the emerging multiplicity of the concept token, as well as project researchers' disciplinary 'hinterlands').

5.2 Problematisation: through the project grant proposal, as well as the project dialogue

The empirical account begins with the first moment of translation. I describe how two of the researchers who had previously worked on the Tivoli project, Nicola and David, formulated a problematisation through a successful grant extension application, before I entered the field. The project was funded by a private, non-profit representing American scholarship in the humanities and social sciences, as a 'digital extension' to the previous Tivoli initiative; this lasted for one year, and I was engaged throughout. I frame the establishment of this grant extension application as an Obligatory Point of Passage, alongside the researcher Nicola and her interdisciplinary 'ambitions', her 'imagined

future' (Jasanoff and Kim, 2015), and her promotion of thought and dialogue around disciplinary working practices. Nicola's position here can be conceptualised as the 'seed' for, or the foundation of, the token of 'the concept encoding a humanities epistemology', which will be brought into this project actor-network during the second moment of translation. The project grant proposal, alongside this aspect of the 'project dialogue' from the initial moments of the venture, helped to fix the parameters for my initial bounding of the network that I call the Digital Humanities project. As in the previous case, the problematisation I describe was actualised, and had the 'capacity' to translate, in potentially numerous different ways. I choose to follow one such process of translation as brought into focus by the concept of 'encoding an epistemology' as the analytical token - one which can productively bring technologically-mediated interdisciplinarity to the foreground.

5.2.1 A Historian and a Digital Research Architect devise a grant extension application, within an 'interdisciplinary' environment

The Tivoli platform project (see figure 26) was part of a high-profile, multi-University collaborative initiative investigating social, historical networks, developing '… interactive visualisation tools [and creating] a repository for metadata on early-modern scholarship, and guidelines for future data capture'. This broader research initiative, within which the Digital Humanities project is also located, received funding in three phases, and I joined the project just after the beginning of the third and final phase in March 2017 – the development of Data Biro. Two researchers from Tivoli - David, a Professor of French and History at University X, as well as the Chair of the 'Division of Literatures, Cultures, and Languages', and Nicola, a Digital Research Architect at University X Libraries, working within the Digital Library Systems and Services group - became the co-PIs of the Data Biro initiative.[73] Together, they direct a programme in an 'interdisciplinary research lab' at

[73] This Digital Humanities project proposal thus represents a point of mobilisation of an actor-network from the Tivoli project.

University X,[74] within which the project which this narrative follows is 'housed'. This is based at the School of Humanities and Sciences and within the Centre for the Digital Humanities, exploring '…digital tools and methods to create new knowledge in interdisciplinary humanistic inquiry'. It is important to note that this 'setting' within which the Digital Humanities project is situated thus lays explicit claim to its own interdisciplinarity, similar to the CGKP as studied by Strathern and Khlinovskaya Rockhill (2013).

In an early interview, Nicola explained that she and David had set up this research 'lab' in 2012 because they '…started to see there were all these flaws, all these problems… which came from a disconnect between the [Humanities] researchers, research questions and the content, and the engineers who build [the Digital Humanities] tools'. Here, Nicola is essentially *problematising* the disciplines, supporting their establishment of an 'ecology' that supports interdisciplinarity. The mission of this group, as described on their official website, is therefore to:

> '… produce, through the lens of humanistic inquiry, new modes of thinking in design and computer science to serve data-driven research in the humanities… In the laboratory environment, theoretical and methodological discussions happen side-by-side with hands-on work with digital materials. Humanities scholars and students, designers, engineers, and computer scientists engage together in ongoing tool design as defined by the specific needs of participating humanities projects'

In an early interview, David also told me about the aims of lab:

> '[It's about] understanding how we need to be injecting humanities thinking into the design of tools. But not only tools, [also] the research process. And so these

[74] Initial contact with the Digital Humanities project included a tour of this research centre during my first visit to University X.

> tools as instruments, they should be a reflection of the research needs, questions and methods. That's ideally what we're working toward' (David)

Once Tivoli had developed out of this lab into 'public' use, requests and suggestions from users ultimately led to the application for a grant extension for the Data Biro project. 'The network view that's in [Tivoli], [the historians] said it's interesting but it's pretty simple and it didn't really satisfy all the kinds of research [they] wanted to do', David told me. The Data Biro grant extension application explains:

> '[The new software will be] a novel type of social network visualisation, one that responds more directly to the kinds of research questions posed in the humanities. It includes the ability to create and edit data directly through the visual interface, and the ability to pull data into [Tivoli] from Linked Data sources. [Tivoli] already supports data import, data exploration, and export of both data and visualizations. Adding [Data Biro] will bring a new interface to [Tivoli] with an even more humanities-centred user experience. By integrating Linked Data, users can also supplement missing edge-data with richer node information, thus developing new methods for analysing social networks'

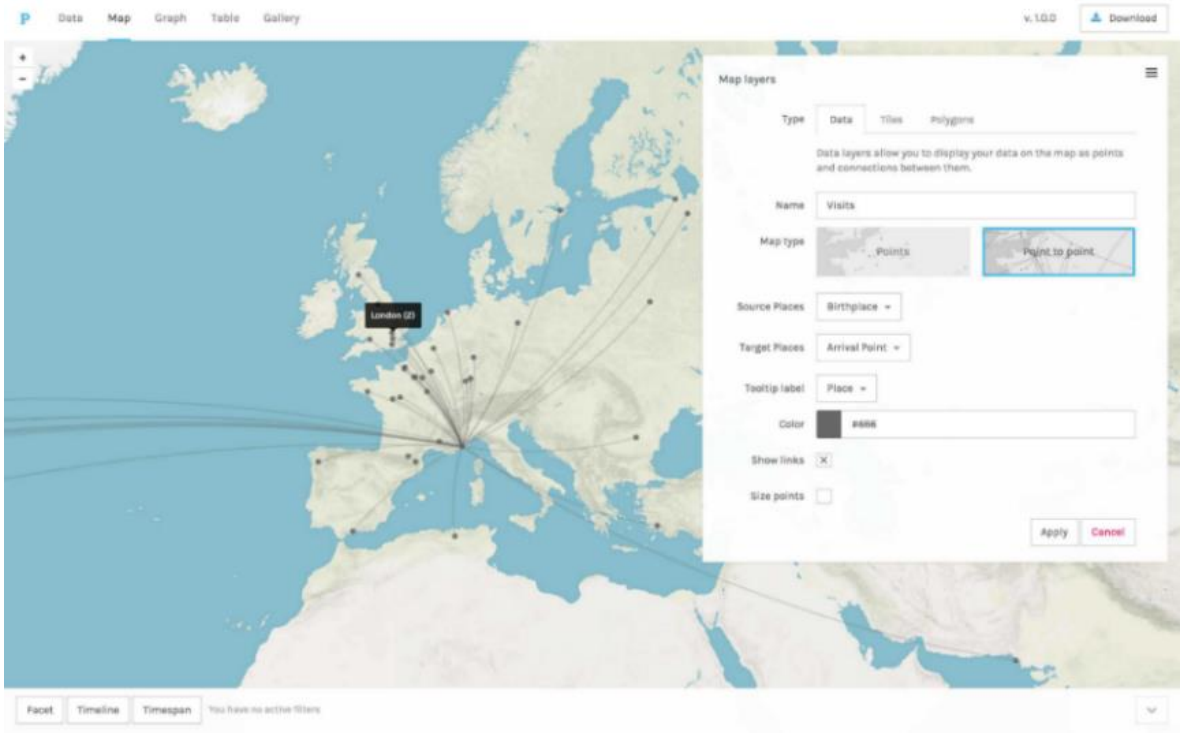


Figure 26. A screenshot of 'the spatial view' from the Tivoli software

Regarding the relationship between Tivoli and Data Biro, Nicola added that:

> '[Data Biro] is formally, in terms of the grant funding, it's an extension of [Tivoli], but really what we ended up doing was re-thinking considerably what was needed and so we built a tool that makes use of aspects of [Tivoli] within it, so it's almost an inversion. Getting data in and then working with it and then getting it out became sort of the most important part of the project, and that was something we didn't really have worked out with [Tivoli], it was more the visualisation only' (Nicola)

'[Data Biro] became a bigger project [than just an extension of Tivoli] in that it's the first data visualisation tool that we're designing that incorporates linked data', David added. David, whilst 'officially' a Professor of French and History, is also widely considered to be an 'expert' in the field of 'interdisciplinary Digital Humanities' at University X. 'I work for the most part on eighteenth-century France, with research interests in literature, history, political thought, and digital humanities' explains his bio on the departmental University

X website. Notably, during his interviews, David discussed uses of Linked Data in the Humanities, as well as speaking in nuanced ways about an emerging 'new field' of 'humanities data visualisation'. Drawing the Tivoli software, along with the (inter)disciplinary actors, concepts and spaces mentioned above, into this emerging Digital Humanities project actor-network, the researchers Nicola and David begin to put forward a prospective alliance of different actors, drawing many from nearby actor-networks, through the grant extension proposal. This sets the stage for the (interdisciplinary) entanglements that unfold in the next three sections on interessement, enrolment and mobilisation in this chapter.

It must be noted at this point that a technological output, the Data Biro software, was not the only 'aim' of the project, particularly from the perspective of Nicola, at the point of problematisation. Development of methodological knowledge, as well as advancing an understanding of 'digital humanities practices' was also a key objective. '[Data Biro] is a tool and an argument', explained Todd, a designer on the team who will be introduced in the next section. 'Definitely some of [the new knowledge produced in interdisciplinary projects] goes to the tools, but then there's a lot of knowledge of understanding the process and understanding how the research questions could be solved. And then the tools are in the end just a small part of the larger process', added Ren, another project researcher who will be introduced later. It is crucial to note that these 'dual aims' (theoretical and technological) underpin, at the point of problematisation, a potential multiplicity (or at least duality) within what it might mean for the project to be a 'success' during enrolment and mobilisation.

5.2.2 Nicola's interdisciplinary ambitions, and promotion of thought and dialogue around disciplinary working practices: the 'seed' for the concept token

From the initial moments of the project, the importance of the articulation, vocalisation and (attempted) externalisation of disciplinary working practices, in order to support

'interdisciplinary' ambitions, is active.[75] This evokes Barry and Born's (2013: 12) comment that 'an intriguing aspect of our research was ethnographic engagement with informants who themselves had cogent analyses of interdisciplinary practice'. This (inter)disciplinary 'self-awareness' is not only present in the 'physical context' of the lab within University X, as presented above, but is also particularly prevalent in Nicola's ideas, and her problematisation of the disciplines and their interrelationships. She introduces these ideas (underpinned by her own assumptions about interdisciplinarity) into this particular project actor-network at the point of problematisation. 'There is a cultural divide between computer science, engineering and humanities… I'm hoping it benefits both of us by trying to articulate externally our procedures', said Nicola. There is in particular a pronounced, self-conscious dialogue with the 'limits' of disciplines, specifically, Humanities and Engineering/Design – which is akin to Barry and Born's (2013) agonistic-antagonistic mode of interdisciplinarity, where, for example, 'the digital humanities are… a driver of monumental and even foundational conceptual changes in many disciplines' (Davidson and Savonick, 2017). For example, during an early interview with Nicola, she told me:

> '[There are many] challenges in working across the disciplines, trying to navigate that space [between the disciplines] …. [Each discipline has got] a certain set of tools [but we need to] step back and really deeply understand the problem and how might we be able to solve it… We bring our training and our experience and you want to be able to contribute so you contribute what you know, and so the interdisciplinarity is just an intersection of those things.' (Nicola)

Nicola, the Digital Research Architect at University X Libraries, views herself as 'sitting between' the different disciplinary researchers working on the project, helping 'communication' between different approaches and viewpoints:

[75] Though there is not one set definition of 'interdisciplinarity' used by the team, as will be explored.

> 'I do my best to try to understand both the affordances on the technology side, and also the kinds of things that… researchers like David [the Historian] want to do… It's often a balancing act' (Nicola)

She sees herself as a 'connector' between the designers, the programmers and the Humanities researchers,[76] and explained to me that she felt it 'liberating' not to have 'training in a particular discipline', which in her view allows her to execute the role effectively. She told me that 'it's very difficult when you are training so deeply in a particular discipline, it's very hard to break out of that way of thinking'. It is important to note that semantically she does not see herself as a 'translator' between disciplines,[77] but a 'connector':

> 'It's not a direct translation because [Humanities researchers] don't always necessarily know exactly what they want or what they're looking for. I mean they know it in their own terms… but specifically it's not translation from one language to another. It's an understanding of practices and methods, and then how we might – let's see, how to put this – when you translate that into a digital context, it's rarely direct, because it's like saying, well what are the affordances of this technology and how might that support what David wants to do. The reason that's such an important role that's often not recognised, because it doesn't have a good name…' (Nicola)

Other researchers on the team also see Nicola as 'sitting at the centre' of the project, orchestrating (interdisciplinary) project interactions, as well as having the clearest project overview – having 'the breadth of vision', said Jim, one of the designers who will be introduced formally into the narrative later:

[76] *Nicola's* division of the project into three groups, in the way she talks about them.
[77] Linguistically, this is a different concept of 'translation' to that used in Actor-Network Theory (ANT) methodologically throughout this thesis.

> '[Nicola] very much is the person standing at the middle… We have these conversations that make it very evident that she's the person who is holding the breadth of the project in her head, in a unique way. That she has the breadth of vision of all our disciplines being significant, which I feel like [makes] it easy for individuals of us to focus on our jobs…' (Jim)

From her perceived project 'position', Nicola's agenda and thus reality-in-the-making drives the 'importance' of the external articulation of humanists' research practices - particularly active in this project actor-network - at the point of problematisation. 'It helps a lot for interdisciplinary work to try to share what your assumptions are', she told me. She explained her personal viewpoint with regards to the necessity for humanists (how the project refers to humanities researchers) to externalise their 'thought processes and methods':

> 'We need to employ humanities thinking, and that's that part of externalising methods that is hard for humanists to do; procedural thinking, that being more kind of computational thinking… And then visual thinking of course, that's another part of externalising the thought process - to the extent that we can do that, it helps a lot for interdisciplinary work to try to share…what your methods are so that you can map from one to another' (Nicola)

> 'The engineering perspective tends to be about, 'give me the problem, and I will find a technology solution for it'. And one of the things we had to explain [in Tivoli] was that we don't have a problem… we want to explore things! But at the same time, on the humanities side, there needs to be a balance of really understanding their own procedural practices. So a challenge that I discovered early on was that the engineers or computer scientists really wanted to work on these problems because they're interesting - the information is really complex, and the questions are deep - but they found humanities methods inscrutable.

> Humanists themselves seem to be often kind of shy about talking about method!' (Nicola)

Crucially, these ideas within Nicola's dialogue can be conceptualised as the 'seed' for, or the foundation of, the token of 'the concept encoding a humanities epistemology', which will be drawn into the project actor-network during the next moment of translation, interessement. Recognising the importance of articulating humanities epistemology, for example, can be understood as the first 'step' to working out how to 'encode' it into a technology. David, the Historian, and Jim, a designer-developer, echoed a similar sentiment:

> '[Nicola was discussing] the articulation of what a humanities research process is. She was talking to us about how she observed over a number of years humanities researchers and how they work… There seems to be this fuzzy, non-specific understanding, and so it seems like a big contribution here is her actually being able to start to pin down methodologically what is going on… When humanities researchers talk to computer science researchers, they have extremely different approaches to the idea of problems and solutions, and so if you're working in an interdisciplinary way and you can't articulate how you want to go about something, or how you would normally go about something, [then] you can't communicate period. So the fact that she's distilling some of that… seems really significant' (Jim)

> 'Humanities methods are very difficult to define, to articulate. And I think it's part of the reason why we don't have that many tools, instruments… it's such an internal process' (David)

Here, Jim in particular recognises the significance of Nicola's ideas, but, as we will see throughout the narrative, stakes little ownership to them within the project. 'I don't feel that it's particularly my research, I just feel engaged in the process', Todd also told me. Nevertheless, there again appears an active problematisation of the disciplines - that is, problematising disciplinary knowledge practices – in an explicit attempt to mobilise an

interdisciplinarity. Indeed, there was a strong tendency during the interviews for the project researchers to 'quantify' (and thus problematise) the (inter)disciplinarity of the project into discrete, and to some extent measurable, levels of 'successful', 'adequate' or 'not enough' interdisciplinarity. However, as previously noted, 'success' was not necessarily defined in the same ways by the project researchers, according to the 'dual aims' of the problematisation, as well as their disciplinary 'hinterlands'. This narrative will show how one success for Nicola would be for her ideas and concepts to be mobilised in others' dialogue, whereas success for the technologists on the project would be for these ideas to be 'translated' into technologies.

Furthermore, this 'quantification' of interdisciplinarity led to some discussions around self-conscious effort towards 'best interdisciplinary practices', or 'true' collaboration.[78] Through, in particular Nicola's, considered promotion of interdisciplinarity, the phenomenon is presented as an ambition (or at least a 'method' to achieve a 'goal') from the project outset – a goal which can begin to be realised through the externalisation of (disciplinary) thought processes. In this way, she has begun to set out a potential mobilisation for the problematisation; a suggested methodology or approach for developing the technology and tackling the project challenges. Almost counterintuitively, however, this is also a sort of 'black-boxing' of disciplinary skillsets and 'ways of thinking', reinforcing a binary or a dichotomy between the Humanities and Engineering – a duality which Nicola had aimed to 'break down' through an interdisciplinarity on the project. As the narrative moves into the next section, interessement, it seems that 'interdisciplinarity is not so much an effect, as an effort, here' (Mulcahy, 2013).

5.3 Interessement

Nicola's (and David's) provisional 'interdisciplinary' system of alliances, as set out above, needs additional negotiations and materials to begin to move reality closer to intentions.

[78] Neither of the other project cases seemed to have an ongoing discourse around their 'own' interdisciplinarity in this way.

These negotiations are set out in this section as part of the second moment of translation, interessement (Callon, 1986). During this phase, additional human and non-human actors will be incorporated to draw allies closer to the framing of the project, and to more closely align their identities and interests with the project goals. One device of interessement to facilitate this is the concept of 'encoding a humanities epistemology' into a technology - the analytical token which, building upon the 'seed' of (Nicola's) ideas at the problematisation stage, is used in this narrative to trace the enactment of interdisciplinary practices in the Digital Humanities project. I show how activities brought this concept to bear on the interdisciplinarity of the project, along with related actors including the diagrams as other devices of interessement. As set out in the problematisation section, it is interesting to compare the *planned* development of Data Biro, and the 'situated actions' through which it is actually shaped and enacted (Suchman, 2007).

5.3.1 'Encoding a humanities epistemology' into a technology: bound with Nicola as co-devices of interessement

As set out in the introduction to this chapter, the token to be followed through the Digital Humanities project actor-network is the malleable, interdisciplinary concept of 'encoding a humanities epistemology' into a technology. This token has a very close relationship with the project aims, as well as the 'interdisciplinary lab' within which it sits, but was not explicitly set out in the grant application. Broadly, it is an 'aspiration' to 'build tools where the tools themselves embody the (humanities) research methods' (Nicola), and which 'reflect a certain conceptual framework about what does it mean to do research in the humanities using data' (David). This is about encoding *into* a technology; an ambition towards the technological 'embodiment' of (inter/disciplinary) practices, built on beliefs, as discussed in the previous section, regarding the importance of the articulation and externalisation of humanists' 'thought processes', working practices and methods. This is about the technological artefact itself having a particular epistemology 'within it':

> "[The historians] are looking at the material and they describe what they see and what's significant to them, and so then the designers are taking this information in and they say, 'oh okay, if that's what is significant to you then we would imagine building a structure like this that would help to emphasise that point'... It's a communication of a particular kind of knowledge, a way of seeing, how can we sort of encode an epistemology into the technology or the design!... [The historians] would not know how to do that because, if we look at training in the humanities, it's pretty much all about writing." (Nicola)

> '[Part of our research agenda is] to see if we can build, create, design useful tools for humanities research that reflect a particular humanistic approach to knowledge creation... Let's build tools that allow experts to bring their expertise to the tool and interact with it - as opposed to, using the computer as a machine to run a pre-defined process' (Nicola)

Crucially, Nicola adds:

> 'My own motivation, what is driving me, is that I think so much of our technology is missing the influence of that humanistic approach, and it must be in part because it's very difficult to communicate those methods. So if we can do a good job of doing these little tests, small experiments – [Data Biro] is ultimately just a tiny experiment - we can do this small experiment to show, no, it is actually possible to encode these methods' (Nicola)

There are two important points to note here. Firstly, Nicola's view of the project as a 'tiny experiment' will be shown to contrast heavily with the technical researchers' approaches to the project as one for technological development and subsequent application, as the narrative progresses. Secondly, the concept of 'encoding a humanities epistemology' into a technology is employed by Nicola to try to complicate the 'binaries' between tool and user, upon which she believes many humanist 'responses' to technology are based. She wants to encourage a 'move away' from potential technological determinism by the team, and in

particular, by the 'techies'. Ewan, an IT consultant on the project who will be introduced shortly, reinforced this when he told me that:

> 'I find this whole thing around research tools really interesting - creating tools that are oriented towards the thought process that people use… This has been a really good manifestation of that approach – as was [Tivoli] – like the sort of design-driven approach, that creates a fairly unique tool that is opiniated about the way it works, but is focussed on… the process of interrogation that humanities researchers are doing… [It's] the overall methodology that Nicola brings to the table… It's a bit of a different methodology that we're still trying to get our hands around…' (Ewan)

Thus, this concept, this idea, is a device used by Nicola to draw other actors, both human (particularly, humanists and engineers) and non-human, towards each other, towards the project goals, but in particular towards *her* ontology-in-the-making; that is, her conceptions of interdisciplinarity (and the field of Digital Humanities), and the way(s) in which she believes interdisciplinarity, in kind – alongside the project aims - should be practised throughout this project.[79]

5.3.2 The initial workshop: interessing actors towards the (interdisciplinary) project

Even though the initial project workshop took place before I entered the field, it is something I explored through interviews and project documents, and which I found to be significant in interessing a number of actors towards the Digital Humanities project. Nicola and David gave accounts of this first meeting and shared the schedule with me. The workshop, which took place at the start of the project's funding period, brought together a number of researchers, including historians, other humanities researchers, and some computer design-developers (with many of whom David and Nicola had worked

[79] An *attempted* stabilisation of reality before the technology is even being built.

previously). Sessions during the three-day gathering included 'What do you want from [Data Biro]?'; 'How should [Data Biro] work? Design challenges'; and 'Defining Research Value: What do you want to see [Data Biro] do first?' Nicola elaborated upon this workshop:

> 'The January workshop involved a lot of people… That's where we were digging into what we really wanted to do, and we gathered case studies… It was a combination of designers and humanities researchers. [A developer] was there, but we didn't have a representative set of engineers to contribute - I think in many ways the engineering is just meant to be in response to what's needed. That was a very productive, intensive three days where we worked through a lot of different scenarios - I [asked humanities researchers for] presentations [about] the kinds of things that [they] had already been doing with data, [and to] share… how they work and what they think would be useful. The idea was that we had a number of designers there who would take that in and try to translate that into something that would work as a visual interactive tool. And that gave us chance to go back and forth, back and forth…' (Nicola)

Nicola's suggestion that there were not many software engineers in attendance because engineering is purely 'in response to what's needed' implies that, during interessement, the discipline of engineering is (already) positioned as an 'outsider', on the periphery of the moving boundaries of the network.[80] This is reminiscent of a 'subordination-service' mode of interdisciplinarity, as proposed by Barry, Born and Weszkalnys (2008), which involves using knowledge from one discipline to 'serve' another – despite what seemed to be a concerted effort towards an 'agonistic-antagonistic' mode at the point of problematisation. It is therefore particularly interesting when David, during his respective

[80] A technologically 'practical' mobilisation already looks less likely at this 'early' point in the four moments of translation.

interview about the initial workshop, argues that Humanists are 'not just guinea pigs' since there is a 'co-creation process' which occurs:

> "We brought in at least 5 or 6 humanities scholars who have some experience in working on historical social networks. And then we also had a bunch of developers … We had some plenary discussions - but we also would break up into groups where we would pair one or more humanities scholars with a small team of developers. The scholar would say, 'these are the kinds of questions I'm looking at,' and the developers and designers would listen and say, 'is this what you're trying to do?' and there'd be kind of this back and forth… - we'd try to translate that into what might an application look like that could do this… It's almost like a translation process… We speak humanist, they speak tech – and so it really is just taking what we're saying as a research question, and trying to distil that into, what kind of functionality are you really talking about?… And the farther removed the humanist is from Digital Humanities, the harder that translation process will be… because we're kind of speaking a bit of a dialect. I guess we [humanists] are not just guinea pigs, because it's not like we've come up with something and then we're trying it out – it is this co-creation process, it's not like one person has the vision and it's put into place…. It is a structure where the whole is genuinely greater than the parts" (David)[81]

Here, David seems to 'defend' against a 'subordination-service' mode of interdisciplinarity on the project, adding that the '…kind of [humanities] data we're working with should be of interest to computer scientists and data scientists… because it has a lot of quirky features' - *despite* his clear recognition of the role of the Historian as the end-user for the technology-in-development. Furthermore, David's assertion that 'we speak humanist, they

[81] This is reminiscent of Berry (2019) who argues that 'the digital humanities can be understood as a set of interlocking and interdependent parts that, whilst distinct and standing alone to some degree, nonetheless adds up to make the whole greater than the sum of its parts. In other words, digital humanities as a coherent, if nonetheless still contested, discipline'.

speak tech', and his discussion of a 'translation process' between technologists/engineers and humanists that this is 'required' to 'remedy' this, is evocative of Nicola's discussion of the necessity to make 'connections' between disciplines on the project. This disciplinary divisional notion, which exists in the minds of the researchers during the initial workshop and throughout the project, thus forms a central motivation for employing the concept of 'encoding an epistemology' to draw together, to interesse, these disparate actors, towards the project framing.

Two further 'key' team members on the Digital Humanities project were also interessed through this initial workshop: Ren and Ewan. Ren, a Computer Science professor from another University,[82] had previously worked on the Tivoli project. Nicola explained that Ren '…is a computer scientist, and he thinks like a computer scientist, but he is really committed to revealing and making available cultural heritage data. He's been working on a number of different digital humanities projects. The fact that he's quite sympathetic and sees the value of this is huge'. Similarly, Ren told me that, 'I said that my reasons for being interested in this [project] are purely computational, computer science, but that's a lie because I am naturally interested in all sorts of weird things, and the humanities has a lot of that!' Ren has previously designed the Digital Humanities module in the Computer Science department for his home University, although in a Slack post mid-way through the funding period for the project,[83] he informs the team that he recently attended 'a conference on studying the 18th century. Interesting for me as my first truly pure humanities conference, but somewhat of a culture shock'. Although he has significant experience working on interdisciplinary projects, Ren does not identify as an 'interdisciplinary researcher'.

Ewan, present at the initial workshop as well – although he admits he was 'mostly listening' rather than participating – also has some interest in the humanities, 'despite' his

[82] '[Ren's team] are really at the cutting edge of linked data research' (David)
[83] Slack is an online communication platform used by the team.

technical background and role on the project. He is an IT consultant from industry employed as a frontend developer for Data Biro due to his work on previous projects with Nicola, and 'has a degree in Philosophy, and he's really interested and excited about this work' (Nicola). Ewan confirmed that his 'humanistic background certainly helped in especially the earlier [project] discussions, to kind of understand how the process works'. As suggested previously, and as the narrative will show going forward, both Ewan and Ren see Nicola as the project 'leader', and both stake little personal 'ownership' of the project: 'I think I haven't worked that much on this project!', Ren told me, with Ewan adding that 'I'm just stuck between everybody!'

Following the initial workshop, two more researchers were also drawn into the 'core team' for the Digital Humanities project. Jim and Todd are both students in Visual Communication studying at a University in Australia. Their supervisors had attended the workshop – having been involved in a previous Digital Humanities project with Nicola - and suggested that their students, Jim and Todd, join the project as designer-developers, 'the Design team'. Jim and Todd consistently work on the same project tasks, explaining that this is a learning curve for them as their first 'big' research project.

Ewan's, Ren's, Jim's and Todd's (and the other researcher's) backgrounds, which I assembled from a variety of data sources, suggest the 'entanglement[s] of networks where their research approaches and practices stem from, how they understand the research question and what their aims are for engaging with the [other] discipline[s] [on the Digital Humanities project], as well as how these have a bearing on their differing engagement with the token' (Rimpiläinen, 2015: 77). It will thus be important to keep in mind that, alongside Nicola's framing of the project at the point of problematisation, the researcher's disciplinary 'hinterlands' participate in generating their realities-in-the-making (Law, 2004). (Inter)disciplinary realities are beginning to emerge loosely around the malleable concept of 'encoding an epistemology' as actor's roles and relationships in the project are negotiated and coordinated.

5.3.3 A (material) device of interessement enters the network: Historians' diagrams as (inter)disciplinary objects

Following the initial workshop, Nicola asked whether any of the Historians who participated were willing to share examples of 'network diagrams' which they might wish to construct in the Data Biro software. As discussed in the introduction to this chapter, these diagrams are brought in at this stage within interessement in order to try to illustrate Humanities' researchers' 'way of working and knowing', their 'epistemologies'; that is, to draw 'disciplinary outsiders', primarily the technical researchers, closer to what the Historians are working on as well as their methods. The diagrams are positioned by Nicola as an opportunity for the project researchers from different disciplines to 'come together' around them, for the technologists to better understand how Historians work. In this way they can be conceptualised as (inter)disciplinary objects, and a material part of the concept of 'encoding an epistemology'. David, the French and History professor, and Alessandra, another Historian who is currently a Visiting Researcher at University X, provided Nicola with some of their hand-drawn diagrams. Whilst I did not observe the construction of these diagrams, I was informed by their creators that they had worked alone and provided examples with which they had been struggling.

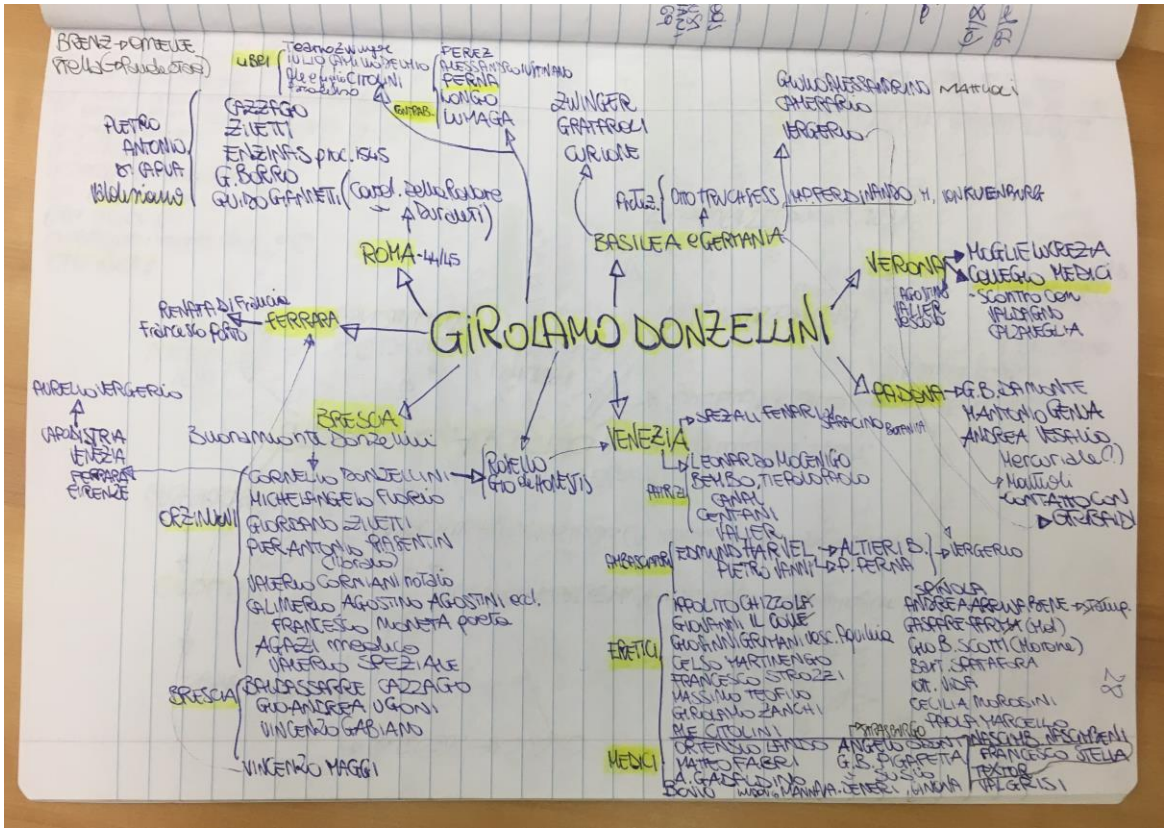


Figure 27. Hand-drawn 'network diagram' by Alessandra, Historian

Nicola explained to the team the relevance of these diagrams, and why she requested them, when she scanned and uploaded figure 27 for the project researchers to access via Slack:

Nicola [7:55 PM] example_graph.pdf

**Use Case from Alessandra* Alessandra has produced a number of hand-drawn graphs. She starts with a significant individual and draws links to places, then to the people the individual encountered in those places. The places most often imply time. The individual travelled and there are often dates, if imprecise, for the periods spent in a particular place. People with whom the individual interacted in those places would inherit those date associations (like an event). Even if it is a 10 year window, it is useful to know who was met then to distinguish from people met 20 years later... Let's experiment with building this graph in [Data Biro] leading with the question, "Why is this better than pen and paper?"*

Nicola [11:48 PM]

...What I shared are various hand drawn graphs to show how researchers do this to "think through" their data and model it "as they go". We need to offer a tool with that flexibility, but which offers and captures data in a standard/reusable format.

Nicola attempts to 'externalise' Alessandra's research practices through the diagram in order to illustrate to the engineers what they 'should' be working towards 'encoding' into the Data Biro tool. The aim is to help better the engineers' understanding of humanists' working processes. In this way, the diagrams, figure 27 and figure 28, can be conceptualised as (physical, visual) partial enactments of the concept of 'encoding an epistemology', the analytical token which this narrative follows. They are the 'first step' of fostering a particular dialogue around (humanities) disciplinary working practices – articulating 'humanities thinking' through an embodiment of the 'humanities epistemology', for the primary benefit of the technical researchers, as discussed above. They *are* research practice; they are designed to 'make visible' humanists' working practices or, indeed, how humanists 'practice' knowledge. The diagrams thus work as devices of interessement in this project actor-network; they are actors drawn into the network in order to support 'interdisciplinary' practices, as conceptualised by Nicola. Indeed, Jim and Todd reflected on Alessandra's diagrams, explaining their significance to them as designer-developers on the project:

> *Todd:* We haven't [met Alessandra yet].
>
> *Jim:* She [draws] these exceptional graphs – they are also, like David's [diagrams], extremely relevant to the kind of work we're trying to do and illustrate a couple of problems that we have talked through.
>
> *Todd:* I found [her most recent diagram] to be an amazing discussion [starter] purely because as soon as we brought it up, it's like, here's a graph that's already done, and it's helped her. It makes perfect sense [and so] what do we offer someone who is already doing fine on pen and paper. I thought that was really fascinating.

Todd and Jim further explained their understanding of the Historians' diagrams during our interviews, in particular referencing figure 27:[84]

> "That image really distils, 'I just highlighted this because it's important to me'. I personally can't tell why because I'm not knee-deep in her research, but here is a highlight – it might mean absolutely nothing, but it might be of huge significance, that's not for us to impose. It illustrated a couple of really key points like that" (Todd)

> "[Looking at the humanists' diagrams], they all had these personal visual languages that obviously they had developed to serve their own needs. And so you have to go through this back and forth process [involving] what information am I actually trying to communicate, how much of it is it worth distilling – is this a connection which means geographically distant, or is this a connection which means 'has worked together'? If it only comes up once it might [only] be an annotation… it can be really interesting to be forced to distil that…' (Jim)

[84] During the second workshop, as discussed later in this chapter, Jim, upon studying a similar network diagram drawn by David, exclaims that 'It's meaningful for David, it's not meaningful for me – but it's legible!'

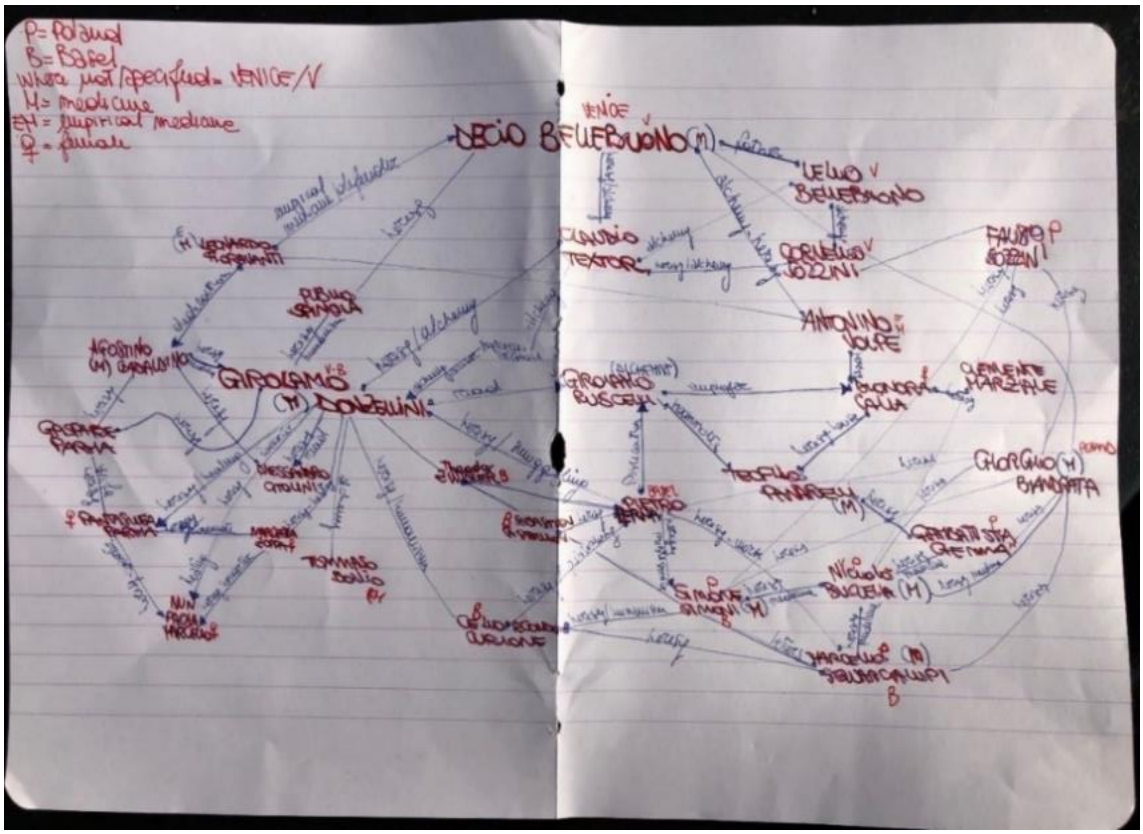


Figure 28. Another network diagram hand-drawn by Alessandra, and shared via Slack

The diagrams can be conceptualised as surrogates for their disciplinary 'spokespeople', representing what's 'important' to these humanities researchers, and thus acting as spokespersons for the subject of Humanities in this actor-network. They are one translation in and of themselves; inscriptions of the researcher's (disciplinary) 'hinterlands'. They retain shape as they enter the project actor-network which this narrative follows; they are one (partial and embodied) enactment of the humanities epistemology, yet 'fluid' enough (potentially) to be 'encoded' into the technology-in-development. In this way, these diagrams can be conceptualised as 'practice negotiating artefacts' (Jordan and Rimpiläinen, 2010: 3), akin to (but not the same as) Star and Griesmer's (1989: 393) 'boundary objects', '…objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites… They have different meanings in different social worlds but their structure is common enough to more than one world to

make them recognisable'. The narrative will re-visit these diagrams during the next moment of translation, enrolment, as a workshop brings explicit attempts to 'practically translate' these diagrams into the Data Biro software; to move the diagram from a (material) domain more typically associated with the Humanities (pen and paper), to one more typically associated with Engineering (software). It is hoped that these, or some form of them, in turn, can be 'encoded' into - that is, 'translated' into or 'rendered' by - the Data Biro software-in-development.

5.4 Enrolment

During the narrative of enrolment, I continue to trace the ways in which the disparate elements I have already introduced become enrolled 'up to a point' (or not) in the heterogeneous assemblages of this particular actor-network. Through this third moment of translation, my narrative primarily will focus on two multi-day 'design workshops', during which time otherwise geographically-distributed actors are gathered together. The workshops took place midway through, and at the end of, the funding period for the project, respectively. My account continues to follow the concept of 'encoding an epistemology' (and its diagrammatic counterparts), exploring its emerging multiplicity (and subsequent tensions), and the extent to which it participates in consolidating the (interdisciplinary) alliances that were initially envisioned by Nicola during problematisation. There is in particular an emerging duality between the concept as purely a 'theoretical' practice, and the concept as it is 'applied' to the technology-in-development, Data Biro (in part, according to the 'dual aims' of the problematisation). Through enrolment, partially shaped by the absence of Humanities researchers, I describe how Nicola's reality-in-the-making jostles to become realised in enactments of interdisciplinarity. As the narrative moves between enrolment and mobilisation, I describe ways in which she (and others) accomplished the concept theoretically, ordering knowledge and identities in particular ways, and displacing other ontologies in the process.

5.4.1 Enrolling heterogeneous actors via Slack: 'gathering' more diagrams and documents, and striving to build 'interdisciplinary shared understanding'

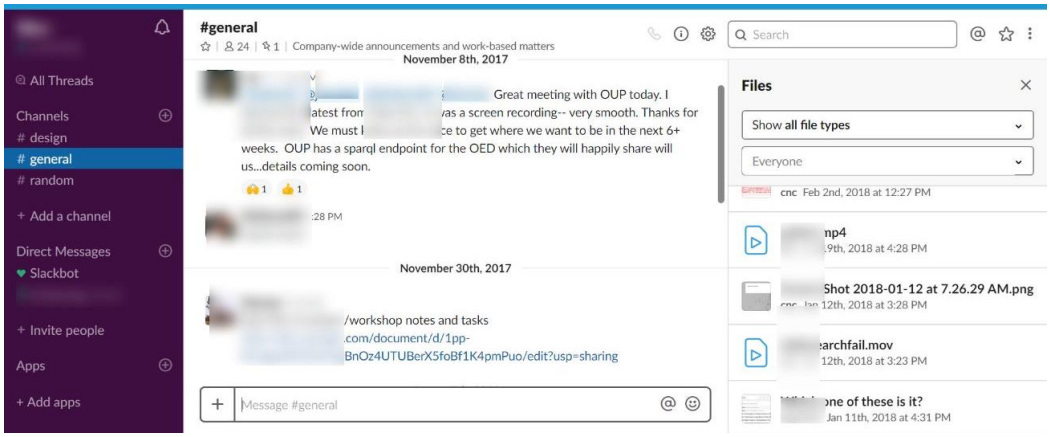


Figure 29. The Slack interface

Due to the nature of the geographically-distributed team, Slack, as well as Zoom, were fully enrolled into this project actor-network before I joined project. Slack is an online collaboration platform (see figure 29), and Zoom is a webinar and videoconferencing package. Most members of the 'core team' in the Digital Humanities project contributed to discussions on Slack at least once a week throughout the duration of the project, across the #design, #general, #weeklydemo and #random channels set up by Nicola. In addition to this, weekly meetings were held via Zoom between different variations of the 'core team'. Other online platforms also enrolled into this project as actors from an early stage, including GitHub and Dropbox. The Slack channels were often used for (un)settling (mis)understandings, interdisciplinary or otherwise, and asking questions. For example:

Jim [2:54 AM]

So is a 'relation' an instance of a type, or am I mixing these up again?

Ren [2:56 AM]

A relation is something that links together instances of types/classes. So e.g. you can have friend/knows/father/son relations between people, and birthplace/deathplace/visited relations between people and places. and birthdate/deathdate relations between people and dates (and "hasGender/isOfGender/gender" relations between people and genders)

Jim [2:59 AM]

Right! Excellent, excellent, excellent. Baby steps. Thanks for clearing this all up for us.

Ren [3:00 AM]

(It can get complicated and depend on particular bits of modelling in the end, so for example you could model a person's death as an instance of Event with associated participant, place and time properties instead of as attributes of the person)

Jim and Ren reflected upon similar examples in their respective interviews:

> 'Talking about frontend and backend language was a really obvious negotiation between the development, like the code of the application understands the terms as such, [and] the human beings on the other end… Even internally it's a struggle to communicate, to link those two things together - the number of Slack conversations we had about what 'enrich' means – and 'expand'! All these proto-names for tools and actions that only exist in theory… mean to me something completely different to Nicola, something completely different to Ren, and so we're all bouncing back and forth on what we're trying to offer, what the researchers might actually want…' (Jim)

> "We're having conceptual issues all the time, defining what 'expand' means… and resolving those is really core because nothing will work if we don't have a shared understanding of what we're doing and why, starting from the humanities needs and passing through that interface design and the technical requirements. I think everyone needs to have some understanding of all of those pieces for the process to continue" (Ren)

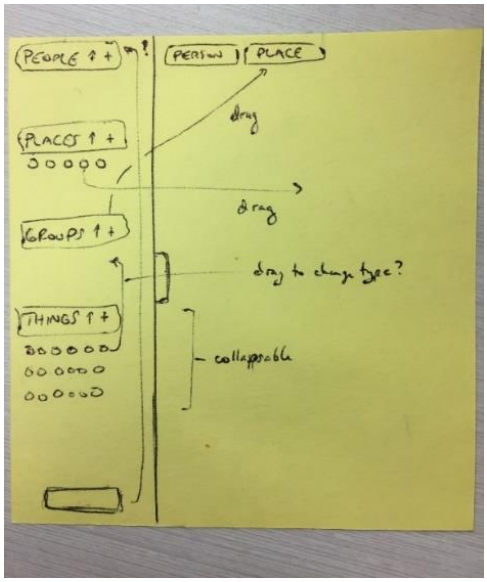
Ren's use of the term 'shared understanding' (regarding linguistic terms, as well as broader project goals) is also reflected by Ewan, who talked about the team building a 'shared language',[85] both online and offline, and more directly by Nicola:

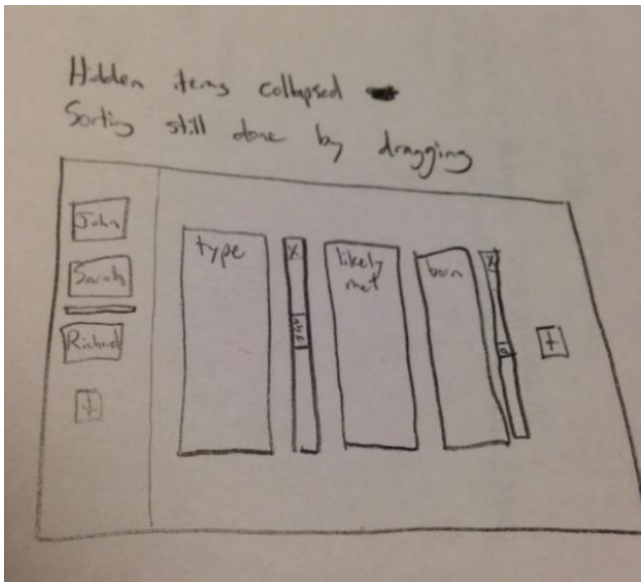
[85] Analogies were often used by team members during the workshops, for example, multiple references to a wedding cake to describe the layers in the tool.

> ‘We had shared understanding of what the purpose was, and what we were getting at, and that takes time…. I think what’s interesting is that though we did build that shared understanding, it doesn’t in any way change that notion of the complementary research agenda, versus shared. [The designers have their] own interest in the project and the intentions and purposes for them are very, very different. And the same for the engineers… It’s not a shared agenda, it’s a complementary research agenda… we’re not actually after the same thing… They’re complementary which means we can benefit from working together…’ (Nicola)

Slack is thus a domain for enrolment and interdisciplinary negotiations within the ‘technical’ disciplines, as well as, to a lesser extent, between these disciplines and the humanities. David, although he has an account, is not active on Slack, and it is notable that when the discussion becomes heavily ‘technical’, Nicola does not engage as much. Nicola is also not very active on the #design channel, and conversation is typically between Ewan, Ren, Jim and Todd. This suggests that, despite her careful theoretical intentions, in practice Nicola does not pick up on the (potential) richness of her ‘concept’ for all disciplines engaging with it, in particular for enrolling the engineers. In turn, this tension begins to narrow the ways in which it might be mobilised ‘practically’ or technologically.

It is, however, the large number of files uploaded to the Slack platform, and how they enrolled, enrolled others, or did not, upon which I focus, due to their significant implications for the nature of enrolment in this case. By the time I had left the field, over 150 project documents, images, photographs, diagrams, sketches, wireframes, Zoom meeting recordings, Data Biro prototype demos, etc, had been uploaded to the Slack platform – including the humanists’ diagrams discussed above. Figures 30 – 33 below show some of these uploaded documents:





Figures 30 and 31. Developer 'starter' diagrams/wireframing (uploaded to Slack by Ewan)



Figure 32. 'Enrich' interface wireframe for Data Biro (uploaded to Slack by Todd)

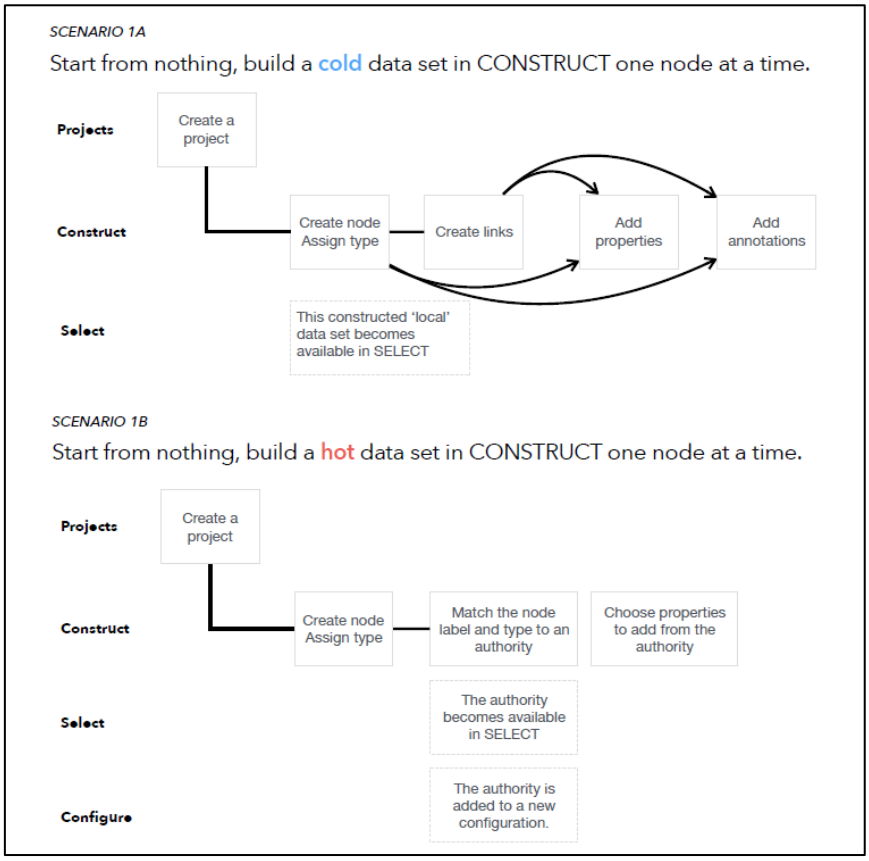


Figure 33. Data Biro 'workflow' (uploaded to Slack by Ren)

Like the Historian's diagrams above, these documents work towards facilitating the 'shared understanding' which the researchers discuss, both by being enrolled, up to a point, and more notably by enrolling others (in particular, the human researchers) into the project actor-network. These diagrams and documents uploaded by the project researchers, again as for the Historians' diagrams, can be conceptualised as research practice, that is, inscriptions, and enactments of the researcher's (disciplinary) 'hinterlands'. The concept of 'encoding an epistemology into technology' circulates, to a certain extent, through these documents and conversations on the Slack platform, working to consolidate (interdisciplinary) alliances, towards a translation. For example, figure 33 illustrates a potential humanities researcher's workflow when building a new project in Data Biro. Ren, the computer science professor who created this and uploaded it to Slack, employed his understanding of how a humanist might interact with the Data

Biro software, in order to produce this (based upon the concept token). At the very least, this meant that he recognised that the humanist-user's workflow whilst using the technology is important to consider. By sharing this on the Slack platform, this diagram can thus be understood as 'encouraging' others to cultivate similar understandings. This is key to how enrolment 'happened' within the Slack space, illustrating how the researchers – primarily the 'techies' - 'came together' around the uploaded documents. However, as will be evidenced in the next section, the notable absence of Humanities researchers, most significantly David, both on the Slack platform as well as during many of the design workshop days, suggests some potentially problematic nuances to the enrolment in the Digital Humanities project actor-network.

5.4.2 Enrolment during the Design workshop, despite an 'absent' Humanities researcher

This design workshop was held midway through the funding period for the project and was designed to foster a further 'encoding' of humanities practices into Data Biro. The Design team and Ewan travelled to University X for the three-day workshop, and thus this was the first of two times when most of the 'core team' (Nicola, David, Ewan, Jim, Todd) were physically together, minus Ren. The team gathered for the duration in a meeting room based the Centre for Digital Humanities on the University X campus which thus enrolled into the network; figures 34 – 36 show this meeting room, including the white board walls which were used extensively by the team during this workshop, as well as throughout the final workshop.

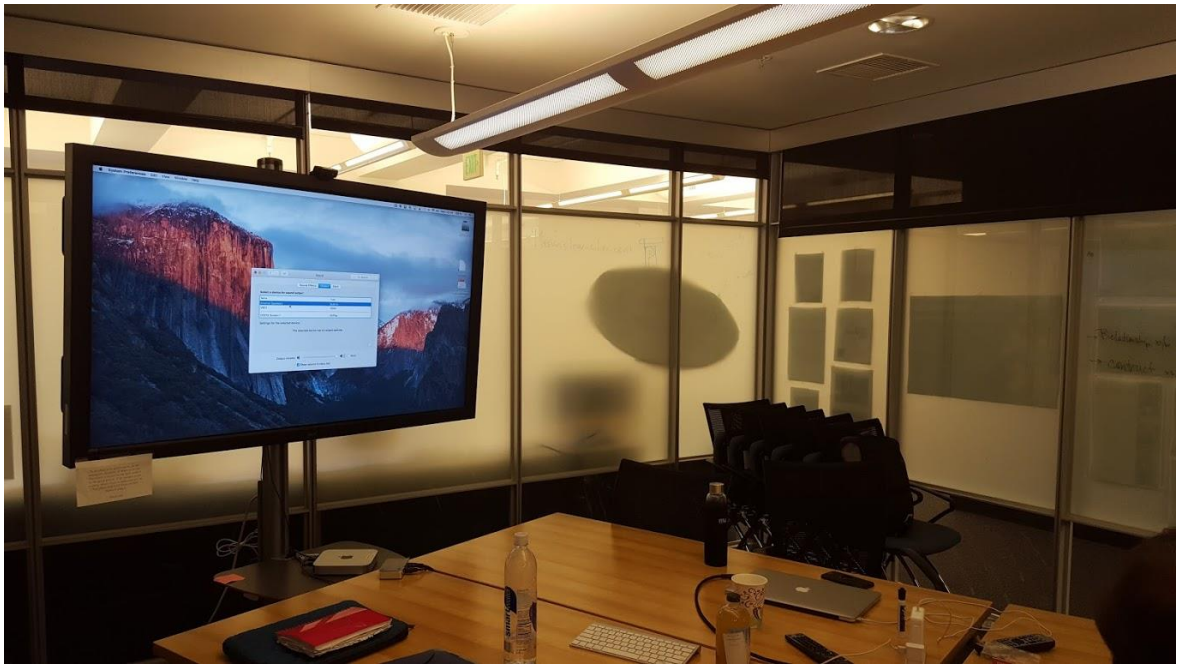


Figure 34. The workshop meeting room (Photo by Erin Young)



Figure 35. The workshop room whiteboard walls (Photo by Erin Young)

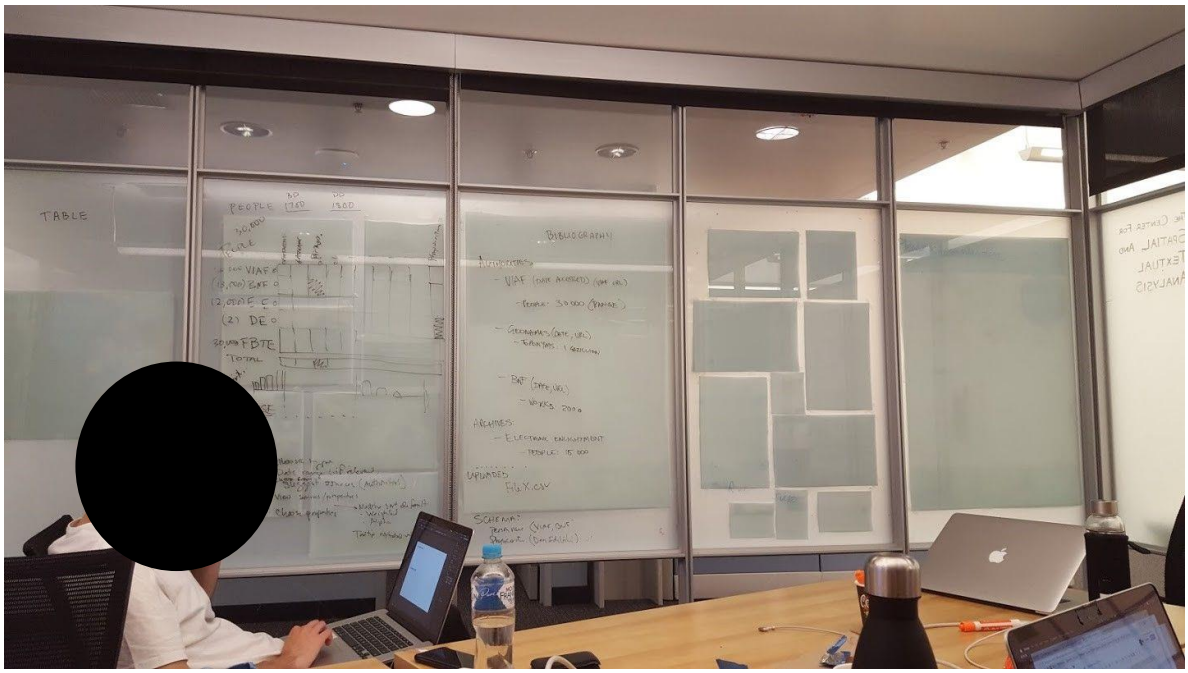


Figure 36. The workshop room in use (Photo by Erin Young)

For most of the first day, Nicola relayed what she understood as 'typical' working methods of humanities researchers to Jim and Todd, the Design team. Ewan arrived at University X on the second day when Nicola re-iterated this sentiment, explaining the need to 'understand how historians think… they're not good at communicating their methods', and thus recapping the foundations of the concept of 'encoding a humanities epistemology', that is, the importance of externalising method. It is notable that during these two days, as during a number of other moments throughout the Digital Humanities project, there was a physical absence of humanities researchers; most significantly, David was not present for most of this time. In these circumstances, Nicola saw herself as 'representing' the views and practices of the humanities researcher 'end-user' of Data Biro. Indeed, during the second and third days of the workshop (for most of which David was absent), Nicola explained how Historians and other researchers have used Tivoli in the past. She did so through a series of diagrams on the whiteboard walls of the room, as well as using analogies and Tivoli demos. Her actions as a 'surrogate' or 'spokesperson' for the Humanists, in their absence, was also apparent during many Slack conversations:

Ewan [5:19 AM]

One other concern is that I'm still having a hard time getting a grasp on what this date range is actually filtering. I think it kind of needs to be against a property, or explicitly against all data-type properties (in the example - is it birth date, death date, or "either" that has to fall within the date range?)

Nicola [8:41 AM]

It is absolutely against a property. In order for this application to work for humanists, we need to give them more control in determining what data they want to select. The timeline could be publication date or it could be birth date or, something else.

David's absences at the workshop, as well as on the Slack platform, suggests a resistance to enrolment; this, in turn, suggests a resistance to (interdisciplinary) enrolment by all Humanities researchers whom he supposedly represents. 'That longer lasting relationship with the (humanities) end-user hasn't formed', comments Ren. This is particularly striking due to David's role at as co-PI on the project, but he discloses that:

> 'The way we work is that none of the humanities faculty really go under the hood much… In a way, we're sort of the ideal naïve users… So Nicola can really think about functionality from that perspective, we are naïvely reigned to [her]. And [she] also knows how to translate that into more technical terms…' (David)

David recognises a necessity for Nicola to act as a 'spokesperson' for the Humanists, interacting with the technologists building Data Biro, suggesting two main points. Firstly, enrolment is not happening in the ways in which Nicola positioned it, with growing resistances to 'interdisciplinarity' by the Humanities researchers. However, secondly, despite a resistance to enrolment by the Humanists themselves, the subject of Humanities – through Nicola, the related concept token and diagram objects – nevertheless enrols to a certain extent.

> 'Compared to other projects, I think [Data Biro] is less interdisciplinary, because we are lacking involved actual end-users of the tool. Nicola is really great, and it's been really wonderful that she's been bringing us these people and their projects and scenarios… and we've gleaned a lot of understanding from them… but in some

> of my other projects, those researchers have then become truly integrated, so the tools are being developed in close collaboration with them for the whole time. I think that could have happened here, but our problem was that our work was for a very long time stalled due to lack of resources, so that tight relationship couldn't form. Or maybe it's the other way around: because it didn't form automatically out [of] the workshops, then the work sort of stalled because there wasn't an actual, outside driver for it…' (Ren)

Ren's view of the project as 'less interdisciplinary', despite Nicola's positioning of the project and its interdisciplinarity, is primarily due to the resistance, or 'failure' of the Humanities researchers/end-users to become 'truly integrated', or enrolled. It could be suggested that this, in part, contributed to a forthcoming lack of technological inscription of the concept token. The *theoretical* enrolment of the concept (as the narrative has illustrated thus far), however, took place due to its closer relationship with Nicola's positioning of the project (who had acted as a 'surrogate' for the humanists), and this will be explored more closely. Her reality-in-the-making jostles to become realised as she (and others) accomplish(es) the concept theoretically, displacing other ontologies in the process.

5.4.3 Enrolment during the Design workshop: accomplishing the concept of 'encoding an epistemology' in multiple ways

The narrative of the Design workshop continues to follow the enrolment of the concept of 'encoding an epistemology' (and how it enrols others) by exploring its emerging multiplicity - in particular the emerging *duality* between the concept as purely a 'theoretical' practice, and the concept as it is 'applied' to the technology-in-development. Following Nicola's explanations of humanities working practices to be 'encoded' at the workshop, during which she told the team 'I'm trying to be as literal as possible to David's workflow', Ewan, Jim and Todd began to mock up wireframes and working diagrams based upon one of David's use cases. 'David wants to explore the relationships between a

number of individuals and their writings in the 18th century to better understand the emergence of the concept of natural rights', explained the use case document uploaded to Slack, created and uploaded by Nicola. Upon reflection on this part of the workshop, Nicola told me:

> 'One moment that has really stuck with me was when the designers were working on the drawing interface within [Data Biro], and they were focussed a lot on shapes… and thinking about those things in the abstract as they would because that's their vernacular… And so what I was trying to explain to them was what is more important for researchers is what those shapes represent, the content behind them, and that's what we really need to focus on. Because these are diagrams that are abstractions, but it's simply a visual placeholder for a much deeper understanding from the researcher the knowledge they're bringing to it…. Designers don't have any of that training [however], and they don't think that way' (Nicola)

This episode suggests multiplicity of the 'abstract shape' objects, and thereby the multiplicity of ontologies stemming from the project researchers' differing (disciplinary) 'hinterlands'. This creates resistances, as well as productive frictions, during enrolment. The Design workshop was therefore particularly interesting for illuminating the emerging multiplicity of ontologies-in-the-making; in particular, the emerging duality, of the concept of 'encoding an epistemology', and the different ways in which the various (inter/disciplinary) actors accomplished the concept during enrolment. For the developers/engineers and designers ('the techies'), it is a task to be completed, something to be technologically built. This could be due to the ways in which they are positioned in the project, as well as their disciplinary 'backgrounds' and assigned 'job roles'. But for Nicola, particularly in the absence of David or another Humanities researcher for the majority of the three workshop days, the concept is not only a thought exercise and a theoretical 'experiment', but also a communication tool. For example, Ren told me, with

regards to the project, that 'I've always been interested in creating or doing applied research and creating tools that are actually useful for someone'. Nicola, on the other hand, explained that 'what we build will not be what people use…it's to work through problems', adding, 'we're doing research, we're not a software development company'. This is about the multiplicity (and utility) of the concept as 'theoretical' practice, which is in tension with Ren's understanding of the concept as something which should lead to technological output. Towards the end of this third moment of translation, the concept as a 'theoretical' practice has thus been enacted; there is not yet a 'parallel' enactment of the concept within the technological design of Data Biro, however. Coordination work thus far has consisted of ontologies-in-the-making jostling for realisation. The narrative of the last section of enrolment, the final workshop, will explore emerging resistances of the concept to translate into technological output, privileging Nicola's enactment of the concept as 'theoretical'. As multiple actors enrol (to differing extents) into their 'assigned' roles, the narrative will continue to illuminate how they negotiated their (interdisciplinary) practices.

5.4.4 Enrolling and displacing during the final workshop: re-visiting the Historian's diagrams

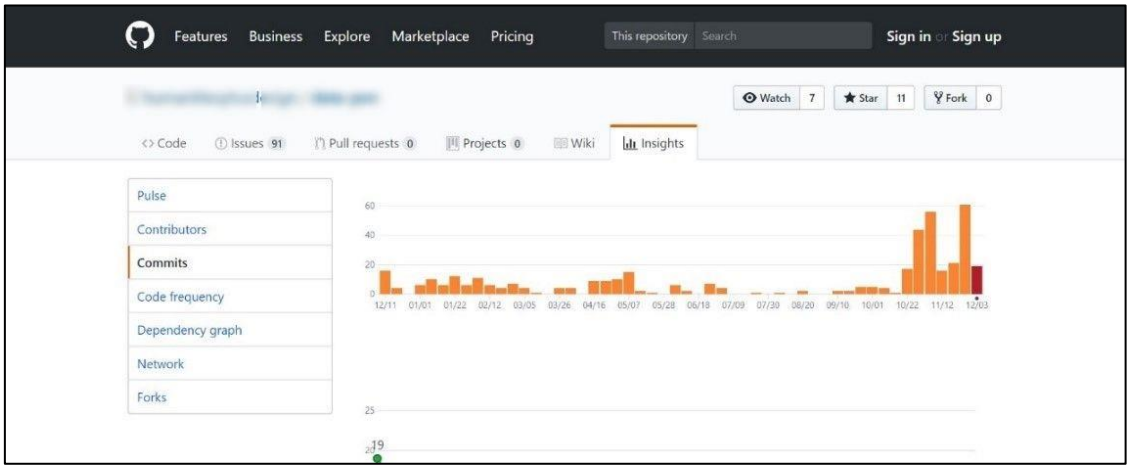


Figure 37. GitHub activity shows productivity 'spike' during the final workshop when the 'core team' were physically together

This workshop took place at the end of the funding period for the project, and interdisciplinarities and disciplinarities continued to unfold in practice during this final meeting. 'The workshops allowed me to understand more of what we're supposed to be designing, and then to actually do the design and figure out my part of the equation', commented Ren upon later reflection. The design team, Ewan, and Ren travelled to University X for this four-day workshop (see figure 37 for activity spike), followed by a Digital Humanities conference at the University, at which Nicola would present their work on the project, and demo the prototype Data Biro software 'if it was ready'. As during the previous workshop, the team gathered in the same meeting room based at the Centre for Digital Humanities on the University X campus. Ewan and Ren are now referred to internally as the 'Development team', distinguishing them from Jim and Todd the 'Design team'.[86]

The first two days saw the team sat around the large, central computer screen, each with their laptops in front of them, working through the software feature by feature, troubleshooting and working out what needed to be done in preparation for the conference demo. As during the first workshop, diagrams were often drawn by members of the team on the room's whiteboard walls to explain their ideas (and 'articulate' their material - 'epistemological' - practices). What was most striking, however, was the team's frequent referencing to Alessandra's and David's hand-drawn network diagrams. This workshop, as for the previous workshops, brought with it explicit attempts to 'move' these diagrams and their features – to 'encode their epistemology' - into the Data Biro software; from analogue/pen and paper (a 'typical' Humanities medium), to digital (typical software engineering media). One episode in particular from this final workshop elucidates the socio-material practices of interdisciplinarity during enrolment. The engineers begin to 'work through' the diagrams, suggesting how they are beginning to value the 'concept' in

[86] At various points during this workshop, they 'break out' into these two teams to work on separate tasks, before coming back together to share their work with Nicola (and sometimes David, if he is present around his teaching schedule)

their work, taking 'on board' Nicola's ideas. For example, the team re-visited one part of a diagram (figure 38), according to workshop discussion around it:

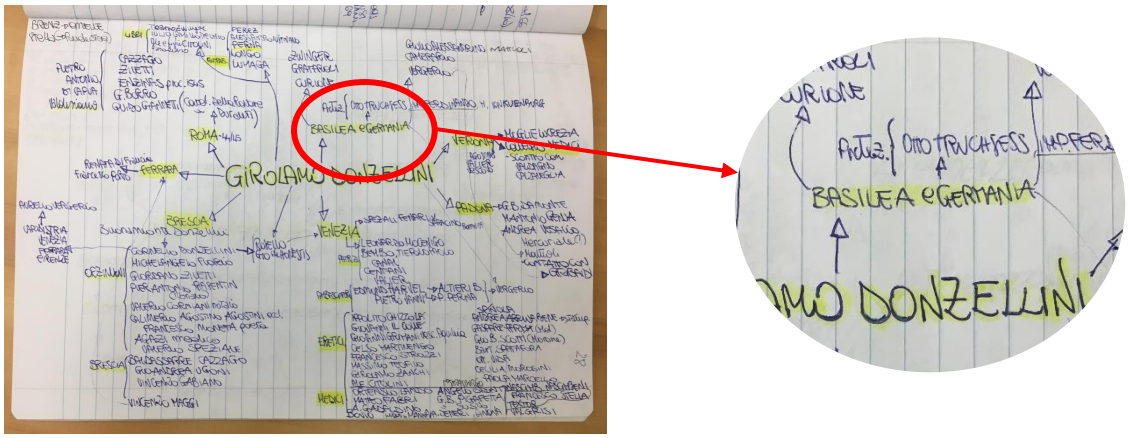


Figure 38. Re-visiting Alessandra's diagram

The team are looking to 'translate' this diagram 'into' the Data Biro software, primarily due to the perceived 'value' of this idea, but also because they know that Alessandra will be present for Nicola's presentation of the project at the upcoming conference. As they study the image, Nicola draws the team's attention to the node 'basil+germany', choosing to use this as a further opportunity to explain the concept of 'encoding a humanities epistemology'. The other nodes highlighted on the diagram by Alessandra are all singular place names/locations, apart from this one. Nicola explains to the team that even if this is 'not a legitimate place, it's still useful for Alessandra', and so this is something they need to 'allow for' in the Data Biro software. These are the 'complexities' within a Humanities 'epistemology' which are seemingly difficult for the engineers to understand: 'I'm uncertain if this is going to be deeply disturbing to you', she tells Jim and Todd, 'but [her diagram] does not need to be readable by anyone else but her, per se. basil+germany is not mappable to anything we currently have [in the software], but she should be allowed to have that, if it's part of her thinking process'. Nicola encourages Ewan, Ren, Jim and Todd to think about what is, and what is not, included in these diagrams, and how this might show what is, and what is not, 'important' to David and Alessandra, the humanities researchers. At this point, Ren interjects with some ways in which they might be able to

include this 'option' in the Data Biro data input interface. 'It's compelling', replies Ewan, 'I hadn't really thought of it in that way before'. In this way, the technical researchers are 'working with' Nicola's concept, enrolling into the actor-network through 'buying-in' to the theoretical (interdisciplinary) concept and diagrammatic counterparts.

On the final day of this workshop, Nicola runs a 'test demo' to three History graduate students, ahead of her demo at the upcoming conference. Alessandra is one of the student researchers present, and so the team decide to 'draw' her diagram using Data Biro for the demo. Alessandra engages keenly, asking questions – themselves, objects of her disciplinary 'hinterlands' – including whether she needs to have a data set before starting to use the software, and what she should do if the 'timeline is complicated'. In particular, she asked, 'if there's a woman, would she be allowed in this network? Because it's alchemist to alchemist but she's not an alchemist'. Jim replied, 'the idea is you're in charge – if you can draw it on a piece of paper, you can do it [in Data Biro]. If any system doesn't let you add her when she is important, then the tool is getting in your way'. Nicola adds that 'we want to allow you to follow the same logic, just a slightly different approach maybe'. Jim has 'taken the lead' where Nicola usually would. The technical researchers have taken the time to consider Nicola's conceptual ideas, internalised them to a certain extent, and are now using them to (try to) enrol others, to 'buy-in', namely Alessandra. This is one 'successful' enrolment for the concept, even if it is not 'making its way' into the technology-in-development, per se; there is enrolment, as well as one emerging mobilisation, of the 'theoretical' concept.

5.5 Mobilisation of Nicola's 'theoretical' concept – and multiple mobilisations of interdisciplinarity

The narrative of the final moment of translation will explore the 'theoretical' (rather than 'technological') performance and mobilisation of the (interdisciplinary) concept token, to a certain extent, representing a privileging of Nicola's ontology. I argue that a 'theoretical' translation of the token happened, up to a point, but that there was not an 'equivalent'

translation of the concept into a 'finished' prototype technology. This was in part due to the duality and malleability of the concept token, as established through the 'dual aims' of the problematisation, as well as the positioning of, and the roles assigned to, the engineers - those 'hands-on' building Data Biro - on the peripheries of the moving boundaries of the project:

> 'I am an observer of things [in this project], instead of me guiding the design - Nicola is the one doing that… I defer to her in all the design stuff even though I don't agree with it… There's different focusses and priorities, so I would focus on different things and do them first, and do some things vastly differently; but I understand her viewpoint on the whole thing' (Ren)

This 'theoretical' mobilisation of the token contributes to researcher understandings of the 'interdisciplinarity' of the emerging Digital Humanities field. Thus, the narrative of mobilisation will also present how interdisciplinarity was performed and mobilised in different ways by different project actors. Project researchers 'understood' and practiced interdisciplinarity (and indeed, the broader field of the 'Digital Humanities') in multiple ways (in large part according to the multiplicity of the concept token, as well as project researchers' disciplinary 'hinterlands'). Ultimately, a 'vision' or 'version' of (Nicola's) interdisciplinarity was actively engaged (both through discussion and tentative design practice), but with project researchers 'understanding' this differently.

5.5.1 A theoretical mobilisation of the concept of 'encoding an epistemology', but a resistance to technological integration

A 'theoretical' translation of the token happened, up to a point, but there was not an 'equivalent' enactment of the concept 'technologically'; the *idea* of the interdisciplinary concept was practiced, while the technological integration ('something to be built') resisted. As this chapter has argued, the concept (token) didn't 'make it into' Data Biro technology at the point I left the project actor-network, when the project funding ended, despite some *theoretical* integration into the interdisciplinary practices of the project. In

other words, actors 'bought into' the aspirations behind the concept, with some theoretical understanding, but there was a resistance to its 'practical', technological inscription and mobilisation. Enrolment (and emerging mobilisation) of the theoretical concept has been illustrated throughout the narrative thus far, and this section shows how the (interdisciplinary) concept of 'encoding an epistemology' never translated *fully* into some 'built' technology, into a Data Biro 'complete' demo. Whilst a demo *did* take place following the final workshop, it consisted of a presentation of some 'simple' features of Data Biro and was not what the researchers 'had in mind'. At this point the software was not a 'finished' prototype, and the demo primarily consisted of discussion around a number of wireframes. Furthermore, near to the end of the funding, prior to this conference demo, David emailed the Digital Humanities 'core' project team, explaining: 'I started playing around with [Data Biro], and immediately ran into problems'. It seems that the prototype did not really 'work' for him, despite his hopes for the software; he has not been enrolled fully into the project actor-network (also due to his absences at the workshops, and Nicola's frequent role as a 'surrogate' for the Humanists). This further suggests a 'failure' of the concept to translate into Data Biro, to be fully 'realised' in technological design and output. In turn, David's usability issues implies that the Historian's diagrams and their features were not adequately 'encoded' into the Data Biro software.

Furthermore, as previously established, according to the multiplicity, and in particular duality, of the concept token, a theoretical mobilisation of the concept represents, in some respects, a 'successful' project for Nicola (where her ideas and concepts are mobilised in others' dialogue), whereas translation of (interdisciplinary) ideas into a technology represents a 'success' for many of the other researchers. For example, as the narrative has shown, for Nicola, Data Biro is a 'tiny experiment': 'what we build will not be what people use…it's to work through problems' (Nicola). This means that a 'technological' translation would not necessarily represent a project 'success' for Nicola - even if it would for the other researchers, in particular the engineers. Thus, the participation and mobilisation of

the 'theoretical' concept, as presented through the narrative of interessement and enrolment, represents a privileging of the ways in which Nicola accomplished the concept, and thus her ontology-in-the-making. This coalescing around Nicola's theoretical 'vision' displaced other ontologies and *their* 'versions' of 'success' for the project. In this respect, this is Nicola's mobilisation (of her 'thought experiment'); a *realisation* of her ontology at this point, which she perceives as a 'success' for the project.[87] Tensions between these 'theoretical' and 'technological' enactments of the concept, and the resistance of the latter, is a tension between Nicola's 'vision' and its resistance to implementation technologically.[88]

5.5.2 The multiplicity of emerging interdisciplinarity in the Digital Humanities project

Despite, and alongside, the privileging of Nicola's 'theoretical' accomplishment of the concept token, interdisciplinarity was performed and mobilised in different ways by different project actors. Project researchers 'understood' and practiced interdisciplinarity (and indeed, the broader field of the 'Digital Humanities') in multiple ways, according to the malleability and emerging multiplicity of the concept token, their own disciplinary 'hinterlands', and the theoretical mobilisation of the concept. Consistent with Nicola's 'interdisciplinary self-awareness' at the point of problematisation, project researchers were forthcoming with their thoughts and opinions on the nature of interdisciplinarity, both within the project, and in the broader Digital Humanities arena. The various ways in which the project researchers describe the nature of the interdisciplinarity within their project, throughout all four moments of translation, is particularly striking. For example, Ren discussed an interdisciplinarity on the project, and in its broader field of Digital

[87] If indeed, as Berry and Fagerjord (2017: 7) argue, the 'digital humanities can offer a critical and theoretical contribution to the key debates around this digital technology and the humanities', then an interdisciplinary 'digital humanities' has been mobilised according to Nicola's (theoretical) enactment of the concept of 'encoding an epistemology'.
[88] This is connected to the 'dual aims' of the problematisation, with the project 'achieving' one of the two (the one 'closer' to the Humanities subject, despite the 'distance' of humanities researchers).

Humanities, which is 'interest-based' and 'necessity-based', with complex interelationships between the disciplines of computer science and the humanities:

> 'Digital Humanities is the application domain of what I'm doing because I'm a computer scientist and my research interests are still purely computational science. But I'm using Digital Humanities as the problem domain for the tools that I'm building… Both the data as well as the problems in the humanities are complex, and traditional computer science methods and tools just don't cut it on humanities data and processes… I think that [Data Biro] is the coming together of my Linked Data past, and the design thinking of [Nicola], that was already evident in [Tivoli]' (Ren)

> 'It's often the thought that, you start with someone in the humanities and then you teach them coding and then they'll be digital humanists. I don't think the works, because… both are full and complete disciplines, and if you try to cram two disciplines into a single person they'll only be sort of half of each and not be able to do either of them properly. That's why I think that these interdisciplinary projects will be much more successful if, instead of interdisciplinary researchers, you have researchers from both disciplines, but only if they are both interested in crossing the divide… A lot of these projects are still such that you have the people in the humanities and they want to do something, but they are not really literate in computer science so they can't say what they want. And the computer scientists are really only interested in their algorithms, and not the end application. Those projects end up with the computer scientists just doing something that they would have done anyway, and that is not useful for the scholars in the humanities. So

> where people still associate heavily with one discipline, for them to collaborate, there really needs to be literacy and interest across the board' (Ren) [89]

Further emphasising his stance regarding the different disciplines maintaining their independent identities while 'taking part' in interdisciplinarity, Ren adds that, '…there has to be this active buy-in into this being an interdisciplinary project, and the belief that there is truly something that my discipline can gain from true participation'.

For David, the Professor of French and History, interdisciplinarity is a 'necessary' context within which to foster a new field of humanities data visualisation. David sees this 'new' field, or inter-discipline, developing *within* the project, and *within* the wider Digital Humanities:

> '[In this project and the Digital Humanities there are] people coming from very different disciplines - design, data visualisation, linked data, computer science, on the one hand – and those are already different disciplines - and then humanities researchers – who are kind of groping together ultimately in what is a very new field. So it's more about identifying and inventing this new field of humanities data visualisation, where neither of us have all of the theories or tools already, and it is about figuring it out together. The process is very interdisciplinary.' (David)

Interestingly, however, he also tells me that he personally tends to prefer the word 'multi-disciplinary' over 'interdisciplinarity', according to his own definitions, when discussing this project:

> 'Interdisciplinary suggests there's this overlap, and we're working in between these two fields which overlap – whereas multi-disciplinary suggests to me, at least, you need knowledge from all these different places, which might be quite distinct - the

[89] Note a comparison to David's comment about 'full' disciplines: '… no one [on this project] has the full expertise, and so we're all dependent on each other, but everybody is also bringing something very specific…. It's great to work on a research project where you feel like a student all the time' (David).

> point of contact could be quite limited, and maybe that's why at the end this point of contact is something which doesn't exist yet, so it's not just like there's a Venn diagram and we're working in the overlap between the two. It's that there's all these fields and there's actually a hole in the middle, and that's what we're trying to fill' (David)

Ewan, on the other hand, does not see such 'radical' interdisciplinarity within the broader Digital Humanities. He views this project as an 'improvement' upon 'traditional' ways of working in the Digital Humanities:

> '[The Digital Humanities thus far] have been humanists wholesale taking up tooling that was developed by technologists for another purpose, or technologists trying to, in some sense co-opt humanistic questions, and just bring a technological methodology… So both directions having a lack of respect for the other side, where humanists would take these technological tools and misuse them, and technologists would take these humanistic questions and misinterpret them in some way' (Ewan)

Jim (and Ren) conceptualise(s) the 'emerging field' as computer science solutions applied to humanities problems, focussing on the 'problem and solution' aspects of interdisciplinarity:

> 'We have all this data, we have an enquiry, [and] as far as the computer science perspective, it's an unorthodox enquiry. It's also a completely normal humanities enquiry. As far as the space of Digital Humanities, it seems very much like it is this collision between these perfectly normal humanities enquiries, and computer scientists with solutions… [But] fraught with all these communication issues' (Jim)

This description evokes earlier moments throughout the narrative referencing Barry, Born and Weszkalnys' (2008) 'modes of interdisciplinarity'; despite what seemed a concerted effort towards an 'agonistic-antagonistic' mode at the point of problematisation, that is,

interdisciplinarity springing from '…a self-conscious dialogue with… the limits of established disciplines… [stemming from] a commitment or desire to contest or transcend the given epistemological and/or ontological assumptions of specifical historical disciplines' (Barry and Born, 2013: 12), some interdisciplinarities within the project are, in practice, more akin to the 'subordination-service' mode. This is particularly apparent in the 'status' of the humanists' as the end-users of the Data Biro software-in-development (rather than 'equal' co-creators, despite their early positioning). Indeed, Langmead et al. (2016: 23) explain that 'recently, humanists have turned to network data to analyse complex historical processes and artefacts. The analysis of networks, also known as graphs, has proven especially useful for exposing and analysing complex patterns of connection— patterns that, at the smaller scale long preferred in the humanities, had generally remained imperceptible'. This reflects the 'subordination-service' mode of interdisciplinarity: 'If we can serve David, we can solve a problem' (Jim).

The broader variations in how these project researchers discuss the 'interdisciplinarity' of the Digital Humanities project suggests the multiple mobilisation of 'interdisciplinarity' as a theoretical 'idea'. These different enactments led to precarious and partial relations within the Digital Humanities project; like the boundaries of disciplines and inter-disciplines, as described earlier in this thesis, the boundaries of the 'Digital Humanities' field in this project are in formation, as the interdisciplinarity of the project emerges. Despite, and in parallel with, Nicola's positioning of interdisciplinarity during problematisation, the project researchers have 'come away' with different understandings and conceptualisations of interdisciplinarity, depending on both their experiences within the project, as well as their previous interactions with the Digital Humanities. The multiple ontologies in-the-making at times hang together so that they appear (partially) stabilised as (interdisciplinary) Digital Humanities, even if this stability is only temporary, and is often displaced by Nicola's ontology-in-the-making.

5.5.3 Summary, and onto the final case

As Klein (2015: 15) argues, "multiple interdisciplinarities are 'in the mix' of Digital Humanities" within this project case. This findings chapter has described how an array of humans and non-humans participate in (interdisciplinary) research and technological development in the Digital Humanities project at University X. Following the trajectory of the concept of 'encoding a humanities epistemology into a technology' (and related material enactments), through four moments of translation, I have explored how a grant extension proposal was tackled in practice when different disciplinary 'approaches', most notably the humanities and (software) engineering, were brought to bear upon it. First, the narrative of this chapter framed how problematisation came about through a successful 'interdisciplinary' grant proposal, accompanied by Nicola's promotion of dialogue around disciplinary and interdisciplinary working practices. Next, I illustrated how actors were interessed towards the framing of this project, primarily through the concept of 'encoding an epistemology', and its diagrammatic counterparts. Thirdly, during enrolment, my narrative tracked emerging multiplicities, and tensions between, the concept(s) of 'encoding an epistemology'. Finally, as the narrative moved between enrolment and mobilisation, I showed how Nicola's 'theoretical' (interdisciplinary) concept was enacted, whilst technological integration resisted. Having evoked the socio-materiality of interdisciplinary practice, it was also suggested that the human participants mobilised 'interdisciplinary Digital Humanity' in a multiplicity of ways.

The narrative of this thesis will now move to the third and final case study – or other instance of the network - the Energy case, where the narrative will continue to illuminate how technologically-mediated interdisciplinary 'research [is] shown to be, like other areas, a realm of socio-material practice – contingent, emergent and messy' (Fenwick and Edwards, 2018).

CHAPTER 6: ENERGY FINDINGS (CASE STUDY 3)

6.1 Introduction

This chapter describes findings from the final case study in this thesis, illustrating the socio-material practices of interdisciplinarity-in-the-making in a third research and development project at University X. The Energy project (2016 – est. 2020) aims to work towards the construction of an improved power grid to minimise the consumption of energy. The ultimate goal of this highly-funded initiative is to develop integrated hardware and software to aggregate and control energy resources, creating a more sustainable and reliable grid to manage renewable energy. This chapter narrative thus follows the Energy project team, both human and non-human, as they participate in the co-construction of this new Energy system,[90] by tracking the trajectory of a token. However, where Medical Robotics followed a technical object (a needle), and Digital Humanities followed a 'concept', the narrative of this case chapter follows a human actor, Marco, a PhD student and researcher in Civil Engineering, through his project interactions. The account will illustrate how Marco's agentic identity emerges and mutates through his (interdisciplinary) associations and relations within this particular Energy project network. By tracing how Marco 'gathers' enrolments of actors, alongside some resistances to 'interdisciplinarity', I aim to draw attention to the interdisciplinary practices around the 'co-production' of an energy socio-material assemblage.

The diagram below (figure 39) represents a 'snapshot' of interactions between human researchers on the Energy project (during enrolment).[91] It is an interpretation of my reality at this particular moment, based upon my data collection and where I have decided

[90] There are 'interdisciplinarity' and Energy studies by Lyall et al. (2011), Sovacool et al. (2015), Naus (2017), Balmaceda et al. (2019), Wong (2016) and Pellegrino and Musy (2017). Wong (2016: 109), in particular, uses ANT as a 'mode of thinking' about interdisciplinary energy research, suggesting that concepts including heterogeneity, enactment, and translation 'can help frame the research problem in a way that could pull together previously divergent/distinct researchers, concepts, devices and data'.

[91] Prior to the Energynet Lab Launch 'integration', as will be described during the enrolment section of this chapter.

to ‘cut the network’ (Strathern, 1996),[92] and does not represent a ‘truth’ or a stabilised reality. As such, it is not representative of the potentially sprawling network of human and non-human actors who were enrolled, or at least ‘engaged’, at this time. Rather, it serves two purposes within this narrative: descriptive and methodological. Firstly, it aids understanding of the multifaceted organisational ‘setup’ of the project, the most organisationally complex of the three case studies within this thesis. Over my first few months in the field, it became clear that ‘Energynet’ actually consisted of two (highly interrelated) ‘official’ projects, due to the division of funding, as well as their organisation across physical spaces at University X, and at the nearby Department of Energy National Laboratory. The ‘x-axis’ of figure 39 shows how these two projects, as well as the technological component development of a cloud device, dimming fuse, and central ‘home hub’, are organised within this. “There’s an extension of this project which is ‘[Energynet] with markets’… we have a pretty solid relationship between [University X] and [the National Laboratory] on this project”, Marco, the human token, told me. The University X (part of the) project is funded by a United States government agency, an arm of the Department of Energy, which sponsors research into energy technologies. The National Laboratory, one of the Department of Energy’s National Labs, is funded by the state’s Energy Commission. It is on the ‘Enerygynet at University X’ (part of the) project that this narrative will focus, but it is notable that the National Laboratory ‘portion’ is drawn towards the University X project framing (by Marco).

[92] The researchers included are those whom I interviewed (and who were mentioned in interviews, observed through observations, and locatable in project documents). It must also be noted that the researchers’ qualifications are assigned according to their current and official ‘job roles’ and departments, but researcher’s nuanced disciplinary ‘hinterlands’ will be explored more fully through the chapter.

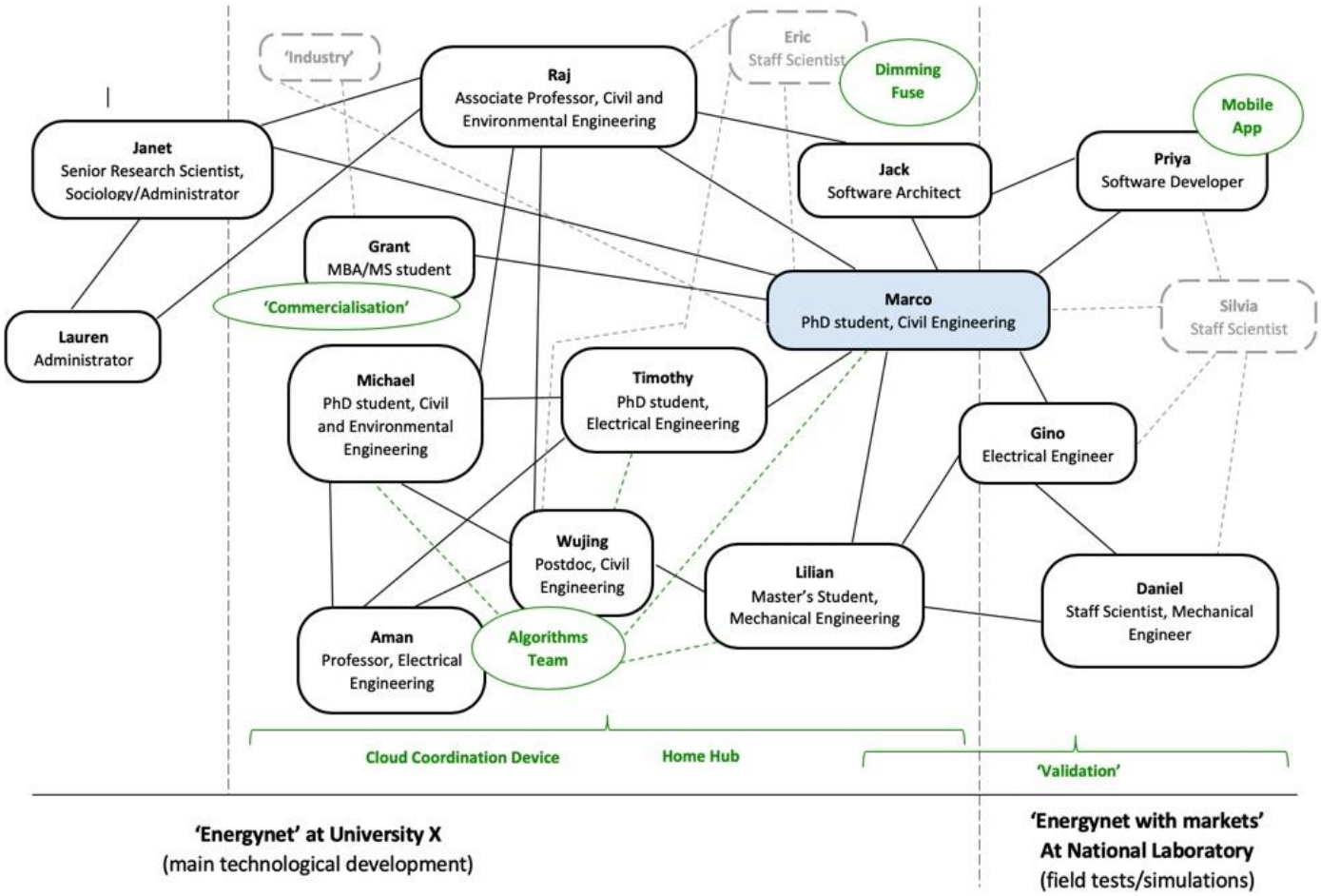


Figure 39. 'Snapshot' diagram of human researchers in the Energy project

This diagram also illustrates motivations for my choice of Marco as the (human) analytical token to follow through the constantly shifting actor-network, and thus the narrative of this chapter. Marco has an Undergraduate degree in controls engineering, a Master's in mechanical engineering, and his current PhD, supervised by Raj, the project PI, is '…in the civil engineering department, but working more with Energy… I am really interdisciplinary… from all different skillsets in engineering… even though I'm doing a PhD in civil engineering, most of my classes are in electrical engineering or mechanical engineering'. As the diagram suggests, Marco has a great number of interactions and collaborations with other actors on the project, as well as across the different, physical project 'sites' (he is doing his PhD at University X, but 'sits' at the National Laboratory for work on the Energy project), technologies-in-development, (inter/disciplinary) researcher 'groups' around different technological components, and between academia and

industry.[93] This is important when considering Marco's increasing relational, 'distributed' agency – and connected interdisciplinary 'status' - within the project network.[94]

This narrative will show how, though rare in ANT studies, using a human actor as the token-to-be-followed can be conceptually interesting: as research and development practices progressed within the Energy case, Marco's agency was constructed. 'The individual is not to be conceived as a sort of elementary nucleus' suggests Foucault (1980: 98). I conceptualise Marco as a 'interdisciplinary knowing location' who '… knows because he… is at the right place in a network of materially heterogeneous elements' (Law and Hetherington, 2000: 4). His identity as such, his ever-mutating 'day-to-day' 'power' in the network, derives from his hybridity (with other actors, both human and non-human) within the (interdisciplinary) network. To adapt Fenwick and Edwards (2010: 21):

> 'What appears to be [Marco's] agency is an effect of different forces including actions, desires, capacities and connections that move through [him], as well as the forces exerted by the texts and technologies in all [interdisciplinary] encounters. While networks and other flows circulate through [Marco's] practices, [his] own actions, desires and so on are not determined by the network but emerge through… the myriad [negotiations between]… the movements, talk, materials, emotions and discourses making up the [Energy project's] everyday encounters'

The process of 'making people' - here 'making Marco' - is a distributed one (Hacking, 1986). 'The human… is not agentic… but is itself an effect of a particular network of associations' (Fenwick and Edwards, 2010: 9), and agency is fostered through Marco's project interactions. He not only transformed, but also multiplied and unified through negotiations within the unfolding and evolving interdisciplinary project assemblage. The chapter will describe how his emerging multiple identities, or roles, took shape as software

[93] I have chosen the phrasing 'inter/disciplinary' to suggest the co-construction of disciplinarity and interdisciplinarity (simultaneously).
[94] Alongside Marco, the diagram also highlights the number of University X students and junior staff engaged in the Energy project.

developer, project manager, 'salesman', as well as an engineering PhD student and project researcher.

This narrative will move through the moments of translation as follows. First, I frame how problematisation came about through a successful grant proposal, underpinned by (interdisciplinary) connections with industry. Next, I describe interessement as actors are drawn towards the Energy project. This section will explore the 'disciplinary' technological development and project organisation, as Marco's (distributed, interdisciplinary) agentic identity is constructed through relations. I will also describe how shared 'visions' of a 'ideal' Energy future, potentially achieved through 'real-world' applications of the technologies-in-development, interesse actors, as tensions between academia and industry arise. During enrolment, my narrative will present a project 'emphasis' on engineering disciplines, as sociology and others 'disciplinary inputs' resist enrolment. The section will then focus on the launch of a project laboratory at University X coordinated by Marco. I will explore the laboratory as a site of interdisciplinary (and disciplinary) multilateral negotiations and integrations; as technologies 'come together' in the lab, so do the human and non-human actors entangled with them, and thus emerge (inter)disciplinary (socio-material) assemblages. This project network does not 'reach' the fourth and final moment of translation, mobilisation. As I exit the field, technologies developed through the Energy project 'struggle' to leave the University environment; the network is not durable enough for representation in industry.

6.2 ('Interdisciplinarities') at Problematisation

In this section I frame how problematisation came about through a successful grant proposal, underpinned by (interdisciplinary) connections with industry. I describe how Marco and Raj, an Associate Professor in Civil and Environmental Engineering and the project PI, along with other researchers based at University X, formulated a problematisation through a successful government grant application, assisted by industry

stakeholders from a high-profile technology company.[95] I joined the project shortly after this funding was granted, and the project grant proposal helped to fix the boundaries for my initial demarcation of the network that I call the Energy project.

6.2.1 Academic, industry and government stakeholders tackle an 'interdisciplinary' Energy problem

The Energy project was primarily conceived as a response to modern day energy challenges, and the necessity to tackle them in 'interdisciplinary' ways. 'Problems that are driven by societal challenges are by definition interdisciplinary because you can't solve them by proving a theorem or by writing a long report – you have to talk to people from different disciplines about how to solve this problem', argued Aman, a project researcher and co-PI who has previous experience of working in 'interdisciplinary' projects. 'The meeting of the problem and the practice really gave birth to the project', Raj, the PI, told me. He explained to me that most of the 'Energy' literature was, and still is, very disciplinary, and that they saw the need for the field to be 'interdisciplinary' – for these different disciplinary areas to begin to 'work together' - in order to have 'real-world' application. In addition to this, he and Marco (the token) explained how a technology industry partner helped devise the focus for the project. The industry stakeholders had been interested in similar problems, but had not made progress:

> 'The concept of the project started a couple of years ago when Raj and I were going to [the high-profile technology company] because they were working on something related to it. There were a lot of discussions, we went there and met with the guys that were working on some of the algorithms… We said we want to get your lessons learned, so that helped us a lot' (Marco)
>
> '[The company] had the wrong assumptions because they were always focussed on where that literature was sitting. So the energy systems guys doing this were

[95] There were also six co-PIs present for the proposal formulation.

> always focussed on power optimisation; the computer science guys were always focussed on the cloud; the machine learning guys only focussed on machine learning. But when [they tried] to put these together it wasn't not working. That's the first major insight we had… we decided to fill that gap. A lot of the assumptions [underpinning] these different literatures and areas were completely disconnected, and we wanted to bring it together… a lot of the solutions in the literature don't work' (Raj)

'Interaction with industry was [a] form of interdisciplinarity', Raj told me, and indeed a number of the project researchers conceptualised 'business' as a 'disciplinary input' throughout my time in the field. This particular company, along with a few other external technology stakeholders, would later join the Energy project's Board of Advisors (although Marco would tell me that 'our Industry Advisory Board, I don't think they're actually really engaged with us'). A 2016 'technical paper' written by project researchers from University X, the National Laboratory, as well as the high-profile technology industry 'partner' who helped to formulate the Energy project, explained that:

> 'We propose [Energynet] as an end-to-end open source technology for economically efficient, scalable and secure coordination of grid resources. It offers integrated hardware and software solutions that are judiciously divided between local embedded sensing, computing and control, which are networked with cloud-based high-level coordination for real-time optimal operations of not only centralized but also millions of distributed resources of various types'

This (early) industry collaboration led to grant applications for funding for a new energy project from two governmental sources, as described above. Daniel, a project researcher who was also involved in the Energy project foundations, who sits at the National Laboratory, and who explained that he has a 'plethora' of experience on 'interdisciplinary' projects which have worked to '…transform the way energy systems work by bringing in

multiple disciplines that normally don't talk to each other', elaborated upon the Energy project funding:

> "…there's kind of two [Energynet] projects, right. So there's the one funded by the Department of Energy, which [is for] technology development… And there's a second project which is funded by the [state] Energy Commission, which is to support some extensions to the work being done under [the DoE]. I think what originally happened was they went to [the DoE] with the whole project and [the DoE] said, 'we can't afford all that… we'll take on one part of this and fund the technology development portion – and then the [Energy Commission] will take on an additional part to do some field demonstrations'" (Daniel)

Ren, a project researcher who will be formally introduced in the next section, added that '…we're trying to bridge a collaboration gap between [University X and the National Lab] and make sure that we're converging towards a similar goal so that we don't duplicate efforts'. An extract from the abstract of the project proposal to the Department of Energy, for the University X (part of the) Energy project – upon which this narrative will focus - elaborates:

> '[University X] will develop [Energynet], an open-source and open architecture platform for scalable and secure coordination of consumer flexible load and [distributed energy resources] DERs… [Energynet] uses a layered architecture that enables real-time coordination of [utilities'] centralised resources with millions of DERs by integrating embedded sensing and computing, power electronics, [data analytics] and networking with cloud computing. The team will develop a Home Hub system capable of networking with… appliances in a home and controlling power via smart switches that replace traditional fuses. The Home Hub will also use algorithms for aggregating local customer resources to meet local constraints and global coordination objectives. A cloud-based cloud coordinator platform will be developed that executes optimisation and monitoring functions to coordinate

> Home Hubs by minimising costs while increasing aggregate consumer quality-of-service.'

There are seven 'Program Elements' laid out in the University X project proposal, as jointly agreed upon by Marco,[96] Raj, the co-PIs, and the funders themselves; these are called 'tasks' in the financial document:

Program Element 1: Development of [dimming] Fuse
Program Element 2: Development of Home Hub
Program Element 3: Development of Cloud [Device]
Program Element 4: [Energynet] Market Design and Analysis
Program Element 5: System Integration
Program Element 6: System Validation
Program Element 7: Tech to Market

'Each of these elements, each of these tasks have sort of a separate discipline', explained Lauren, the project administrator and financial manager, who '…worked for eight years as an engineer. That's a significant reason why I got the job… I can break down and understand a lot of, not all, of what they're discussing when they talk about circuits and electrical sensors'. Each of the programme elements, or tasks, are broken down into sub-tasks, and individual 'milestones' are 'sub-tasks in each sub-task', she also clarified via email.[97] The 'official' University X Energy project website (and accompanying pamphlet, available from the 'Energy building' on campus) explains that the Energy project aims to develop:

> '…integrated hardware and software to aggregate and control local energy resources. Our layered architecture should enable networked neighbourhoods by the thousands to be aggregated and participate in wholesale electricity markets as

[96] The nature of Marco's role within the project during problematisation suggests that, while he isn't a co-PI, he also has a lot more 'influence' than a 'typical'(!) PhD student.
[97] It is around these milestones that the team primarily work and root their short-term objectives. 'Milestones are the primary driver [for the Energy project]', commented Jack, with Janet echoing that the project will be 'driven by the milestones'.

> both buyers and sellers to keep the lights on at the lowest cost… If successful, we will have contributed significantly to building a clean, reliable and affordable electricity future'

This optimistic 'vision' of an energy 'future', achieved through applications of Energynet in the 'real-world', is initially constructed during problematisation, but will be discussed during the interessement section of this narrative (as a device of interessement). Nevertheless, it is important to note here that it was this 'vision', this potential for positive 'impacts' of the Energy project technologies in (interdisciplinary) real-world applications (through technology transfer into industry), that had originally framed Marco's motivations not only for joining the project, but also for (actively) problematising (in certain ways) towards the project construction which was settled upon:

> "What really brought me into the project was the technology, and how we can take something from academia to the market. I'm not the kind of person that's like, 'oh I want to publish papers'… I just want to build something that can actually go to the market. [The funders are] mainly focussed on developing technologies to go to the market. So that's the main goal of the project, to actually have something that the industry may adopt in the future" (Marco)

The geneses of Marco's interdisciplinary identity, and thus his growing competencies in shaping the interdisciplinary Energy project network, are emerging. His emphasis on the importance of commercialisation and application of the Energy project technologies-to-be-developed (corresponding to 'program element 7'), over-and-above the project's value as an academic endeavour - and in line with the funders' views - is prominent. Marco's framing of 'interdisciplinarity as application' will be further discussed during the interessement narrative (and the 'lack of mobilisation' section) of this chapter, as tensions emerge between the Energy project as 'research' or an 'applied project'. At the end of problematisation, however, the research proposal possibilities remain as *possibilities*, and additional materials and negotiations will be required to move reality closer to the

(interdisciplinary) project objectives. Marco has helped to define the problem, in a powerful form of 'gate-keeping': 'I think [Raj] relies on me', Marco told me. Multiple 'interdisciplinarities' are in-the-making, and these will continue to be constructed, made and un-made, as part of my account of the next moment of translation, interessement.

6.3 Interessement

During interessement, I describe how actors are drawn towards the framing of the Energy project as their 'terms of involvement… are negotiated and established' (Nimmo, 2016: xxxii). The narrative of this section will explore the 'modular' (disciplinary) technological development and project organisation, as Marco's (distributed) agency emerges through (interdisciplinary) relations. I will also describe how shared 'visions' of a 'utopian' Energy future, potentially achieved through 'real-world' applications of the technologies-in-development, act as a device of interessement, as tensions between academia and industry, and thus some resistances to interdisciplinarity, begin to arise.

6.3.1 'Modular' (disciplinary) technological development and project organisation, as Marco's (distributed) agency emerges through interdisciplinary relations

It was decided that team meetings would be held weekly at the 'Environment and Energy Building' on campus, with absent participants 'Zooming' in via video conference call.[98] I attended many of the (typically, hour long) weekly team meetings, and I was also invited to attend multiple smaller project discussions between researchers. Meetings were most often opportunities for researchers to update the rest of the team on their work, draw

[98] Researchers varied widely regarding their views on the (interdisciplinary) 'utility' of the weekly team meetings: 'I only attend some of the meetings whenever the topic that's coming up is something that's relevant to the simulation I'm doing' (Daniel); 'the weekly team meeting is definitely the least productive!' (Timothy, a student); 'some of the discussions aren't applicable to say 90% of people there, but it's good to hear and learn a little bit about it, and maybe something is said that you're like, oh you know what, I've experienced this before, let me help out and provide some feedback' (Jack).

diagrams and ask questions about their own and others' work.[99] Towards the beginning of the project, meetings were organised around the progress of 'programme elements' 1, 2 and 3. These 'programme elements' broadly reflect the development of three technological components; the dimming fuse, the home hub, and the cloud device, respectively. The Energynet pamphlet and official website explain these three 'components' in the context of the Energy project goals:

> '[Energynet's] novel [dimming fuse] will replace traditional home circuit breakers to control electricity use based on residents' preferences, while also improving safety.'
>
> '[Energynet] researchers are developing a Home Hub to enable consumers to control their energy consumption, participate in aggregation services, save money and make the most of their home batteries, solar panels and other devices…Based on learning consumer choices and electricity prices, for example, the Home Hub will know whether output from a solar panel should be used, stored or sold, and then act accordingly… The [Energynet] team is developing the hardware for the hub, consisting of a computing unit that runs Home Hub's software and optimisation algorithms… The hub will also include an interface for users to monitor and control their system from web applications and mobile devices…'
>
> '[Energynet's] Cloud [device] will optimise net load for a given area and for each Home Hub within the area to minimise total cost… In addition to communicating with homes, the cloud-based platform will use signals from electric utilities and grid operators—regulation reserves, ramp rates, market prices, etc.—and grid data, such as voltage, frequency…'

[99] Team meeting minutes (including 'action items' and attached photos of any diagrams sketched in the meetings) were written by Lauren, who joined the project halfway through my time in the field. Minutes were regularly sent to the project email list, of which I was a part.

Marco explained why he and the other project co-founders had decided to divide the project into seven 'programme elements' [100] and three technological components:

> 'We structured the project in that way because there are three different main components that are, kind of separate pieces, or separate skill sets or expertise that we need from each individual participant in the project… they don't have any interconnection as of now. So the approach that we took was, okay, let's develop first the components separately, and then as soon as we have something that we can put together, we start interacting between these groups… We decided to break it down at the beginning and then start converging at the end' (Marco)

Marco's explanation of the initially 'modular' project organisation echoes Lauren's assertion that '…each of these tasks have sort of a separate discipline'. Raj and Michael, a PhD student in the Atmosphere and Energy programme in the Civil and Environmental Engineering department, supervised by Raj, who works on cloud algorithms and data analytics on the Energy project, added:

> 'In the beginning because you really need to understand well your little domain, and then be exposed to the holistic thing so you can understand it… You first learn your domain, then you kind of cross over…' (Raj)

> '[The project] seems fairly self-contained in each portion… I don't know if all the time it feels like I'm in this interdisciplinary group… I'm just able to focus on my part…so far all the pieces have been kind of stand-alone' (Michael)

Their comments reinforce the *disciplinary* practices taking place within each of the technological development element groups during interessement. 'As of now I don't think it's interdisciplinary at all for the sub-groups… [they are] working isolated in their own world', Marco, the (human) token, told me, '…people are only working on their own expertise, so it's not interdisciplinary for them in that sense, but the project itself is'. This

[100] 'We've decentralised everything so things can move quicker' (Raj)

was further supported by other reflections at this early stage in the project; for instance, Janet, [101] a senior research scientist and administrator, who is named as 'Project Coordinator' in the Energynet brochure, explained that 'I don't work hard to try and understand everything that [the rest of the team] are doing… I don't try to understand their algorithms along the way'. Wujing, a postdoctoral researcher working on the project's 'load modelling', who has an Undergraduate degree in Computer Science and a PhD in Electrical Engineering (in power systems), and who says her background is 'super interdisciplinary', also told me, '…my work is just on my own… in the small element group. Everyone is trying to work on their own things first, [and then] we all will converge ultimately for the [system] to work… that's the ultimate goal'. It is clear that the *intention* is for the technologies-in-development, and their corresponding development 'groups', to eventually converge; in other words, that they will enrol into the Energy project actor-network as it was set out at problematisation. Further interessement is needed, however, to 'lock' these actors, these technologies-in-development, into the (interdisciplinary) roles proposed for them.

Despite this modular development, however, team meetings exposed project researchers, most notably Marco (the token) who attended and led the majority of the meetings, to the progress of the different (disciplinary) development groups. Marco's status here as a device of interessement is enacted; that is, how he interesses allies towards the interdisciplinary Energy project network, according to the framing he helped to formulate. His agentic identity as an interdisciplinary actor is distributed, sitting between and across the technologies-in-development and their respective, disciplinary clusters of actors. 'The core team revolves around Marco… you have different tasks for this project [and]… people are assigned to those tasks [but] Marco… engages with all parts of it, he understands all

[101] I met with Janet, the 'gatekeeper' of the project, during my initial visit to University X. Following this conversation, during which an outline of the project was presented to me, it seemed an interesting case choice since the disciplinary 'make-up' of the team – a measurement through which interdisciplinarity is 'traditionally' deemed to be quantifiable – was not as 'diverse', since the majority of project researchers at that time came from an engineering background. This is reflected in the narrative during enrolment from the researchers' points of view, too.

parts of it, including the tech-2-market', Lauren told me. Alongside his roles as PhD researcher and project 'co-founder', here Marco is emerging as project manager; his agency is multiple and is increasingly distributed across (and constructed by) actors within the constantly moving assemblages of the Energy project. Marco's evolving role as a 'connector' between the different (disciplinary) 'modules' of the project was also described by Raj at a later point in the project:

> 'I am passionate about all these different modules… The fact that I like all of it makes me educate myself, not to the same depth on everything, but enough so that I can understand how this puzzle fits together… I was constantly trying to connect things, and now Marco is playing that role… the home hub he understands well, he understands the cloud, he learnt how to make the appliances turn on and off, he built the hardware for that with some students…' (Raj)

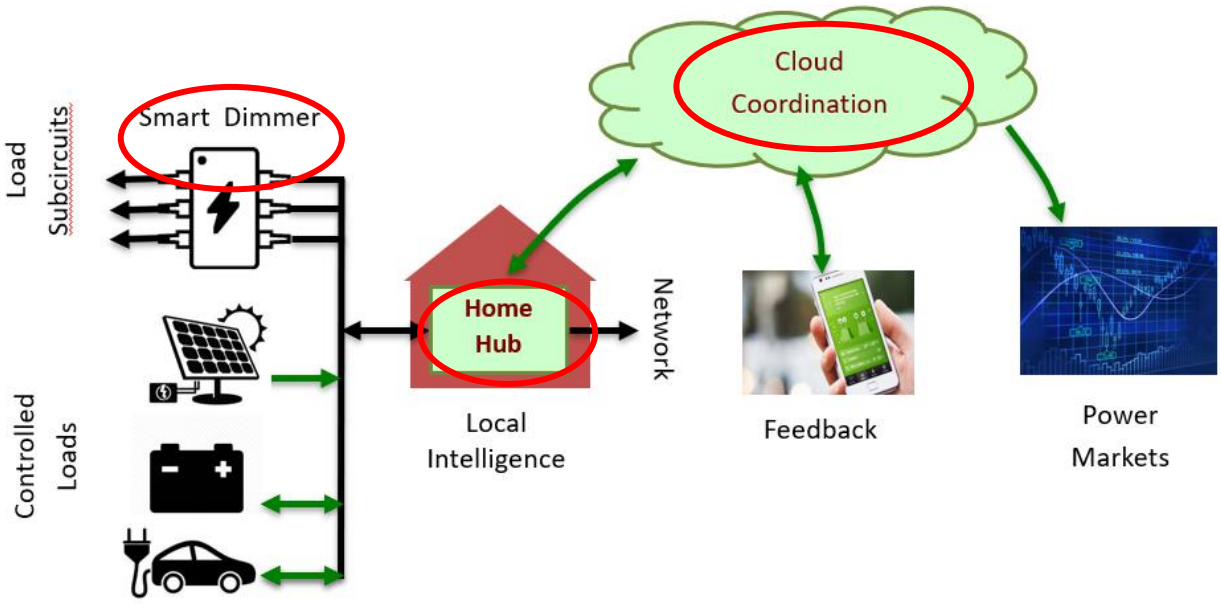


Figure 40. Diagram of proposed interactions between the technologies-in-development (circled: cloud device, home hub and dimming fuse) from the Energy project pamphlet

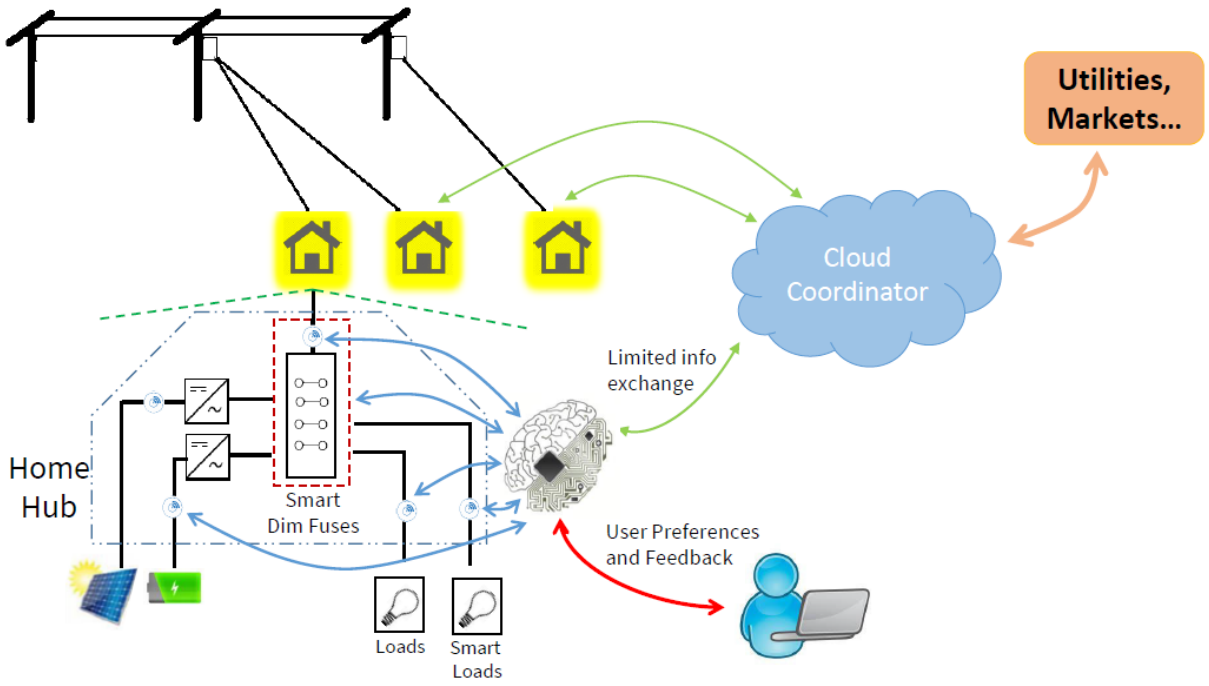


Figure 41. The proposed, integrated Energynet system from a presentation to the funders

Figures 40 and 41 illustrate how it was proposed that the different 'elements', 'pieces', 'components', 'sub-groups' – as they are variously termed by the researchers – will 'come together'. Tentative, multilateral collaborations between the 'modular' groups and technological components begins to emerge during interessement,[102] partially through Marco's developing role as a project 'connector', and Michael added that, "...it's been pretty modular [but] you can get a bit of information in between these different groups: like, I say, 'what are the capabilities of like the [fuse]', for example, and then I kind of incorporate that into my algorithm". Lauren and Aman told me that:

> "From a technological standpoint, they've broken down the key items to talk about. They are a little bit more interwoven than that, though... the [cloud device] will do some global optimisation, but it also has to integrate and talk to the home hub, and

[102] During one team meeting, Raj told those present 'besides your research, make sure you talk to other people... make sure you understand other projects within [Energynet]... maybe what you're doing is helpful to them... Communicate more with different parts of the project'.

> give the home hub some input for what it does. The [fuse] is integral to both of them because the communications and optimisations that go across them are really important" (Lauren)
>
> 'It seems like there's quite a bit of overlap between what people do. I mean clearly each person is doing something different, but… I feel like it's more integrated… I don't see that it's completely separate' (Aman)

Despite these indications of some early 'integrations', however, more work is needed to move the technologies-in-development towards their potential interdisciplinary realities. 'Because there are three distinct technology elements, the coordination across those elements, I would look at that as a risk - that there's too many siloes, and these widgets may not end up working together very well if they're developed in a silo and singular track', said Grant, a joint MBA/MS student at the University X Business School and in the Environment and Resources Master's programme, working part-time on the Energy project. 'I think we're going to face a really challenging future, to try and connect all these things and ideas together', Marco added, echoing not only his role as 'connector' and coordinator between these (disciplinary) groups, but also suggesting emerging resistances to interdisciplinarity by the technologies themselves.

6.3.2 Interdisciplinary applications in a utopian energy future 'vision', with some (academia/industry) tensions

Shared 'visions' of an ideal 'energy future', which may be achieved through successful, 'real-world' applications of the technologies to be developed by the Energy project, are enacted as a device of interessement through the framing of the project (as partially shaped by Marco, the token). The official project website (as well as the publicly available Energynet 'pamphlet') reflects this, equating 'success' for the Energy project with its facilitation of the idealised 'energy future' laid out at problematisation:

> ‘Picture a world where most of the electricity we use is renewable, affordable and reliable. Imagine consumers making this possible by occasionally and automatically selling electricity to the grid or delaying use, usually without even noticing. Much work is needed to create this future, but the electricity paradigm that has served us for more than a century must fundamentally change… Fortunately, today’s sensors, power electronics, algorithms and data science can help the grid manage extensive renewable generation and make the most of new, local energy resources, like residential solar power, home batteries and flexible consumer demand.’

Many project researchers reflected this aspiration towards such a future energy ecosystem; for example, Janet told me:

> ‘The most interesting thing [in this project] is to get a glimpse of the future, because this is early-stage work…. communities sharing energy, sharing storage, sharing energy consumption, so I think it’s a Brave New World of thinking…’ (Janet)

Janet has worked with Raj, the PI, in different capacities and on different projects since he joined University X in 2010. She has ‘a long career of working in interdisciplinary work’ and describes herself as ‘[one of those] people who don’t come from particular disciplines but provide the glue that makes this kind of work go on’. Indeed, Janet recognises that the Energy project researchers ‘…articulate this party line of [Energynet], what it can do, how it’s perceived’. For instance, Jack, a software architect on the project who doesn’t consider himself ‘as a researcher’ because he is from industry (and this is his first experience of research in a University environment), told me that, ‘I think [Energynet] does have the capability to disrupt the power market in a positive way by empowering the end consumer to make better decisions with their energy consumption’. The vision of an ideal energy future brought about by Energynet is indeed an ‘influential’ actor, and Lauren added that:

> ‘I’m really 100% in with the whole concept of the project in terms of upgrading the power grid. I’m excited about the idea of using those distributed energy resources, of aggregating… of getting everybody to have solar panels, drawing from those to

> support the grid or to support independence from the grid when something goes wrong. It just seems very much the long overdue next step in the 21st century!' (Lauren)

These potential positive and significant contributions that the applications of the Energy project's technologies-in-development could have towards a 'utopian energy future' excite many of the researchers, interessing them towards the project framing as they 'buy-in' to the vision set out at problematisation by Marco and the other project founders:

> 'I've always felt like I don't fit squarely into Mechanical Engineering … I guess I've always identified more with a certain application – I've always been very interested in Energy rather than just Mechanical Engineering, so that's what drew me to this project - the goals and the purpose of it' (Lilian)

Lilian, who works primarily on project simulations, and Timothy, working on storage control algorithms within the project, are both University X students.[103] Lilian is a Masters' student in the Mechanical Engineering department who spends 'less than 40%' of her time on Energynet (and attends 'weekly smart grid seminars' at University X which are 'a really valuable resource' for informing her project work), and Timothy is a second-year PhD student in Electrical Engineering. Both students are likewise interessed by the potentially positive applications which the Energy project technologies might have, explaining that '…the most exciting thing would be if the algorithms actually get implemented in real equipment, like in a real setting… a very big part of [Energynet] is practical application' (Timothy). Crucially, as laid out in the problematisation section of this narrative, these applications are by their nature 'interdisciplinary'. Indeed, Grant, working on the Energy project because it '…fits so squarely where I want to work which is in the smart grid, and technologies around the smart grid', argued that 'I do think it's out of a drive for impact that this interdisciplinary harmony comes into play'. 'The topic itself

[103] It is important to note here that time within the four moments of translation is *not* necessarily temporally linear. Thus, during interessement, Lilian and Timothy can reflect upon project practices.

[is] a bit of a collaboration landscape', he added. Grant previously worked at the Department of Energy as a technology development manager and was brought onto the Energy project to help with '…where their technology maybe has some immediate market relevancy', in line with Marco's (the human token's) ambitions for the project. Grant told me that:

> 'I think that [the project researchers] understand well that considerations outside of pure engineering or outside of pure civil and environmental stuff need to be fundamentally built into their research agenda and technology building from the get-go, rather than kind of tacked on at the end. I think that's largely driven by a few team members that came from industry… they understand well that the business side needs to be forefront in design and development… Product development starts when the tech development starts, so when you marry those up, I think you get a pretty cohesive understanding of how these disciplines are going to fit together… with this grant, it's built in the DNA of the project itself' (Grant)

Grant's comments about project work 'outside of pure engineering' will be attended to during the next section of the narrative, enrolment, but his remarks here suggest his understanding of the Energy project as predominantly that of a technological product development project. The "…potential for commercialisation [in this project]… if we do the right thing, not with a 'researcher-mind' but with an industry or start-up kind of mind" (Marco) is clearly important if the technologies-in-development are to 'reach' application in the 'real-world'. This is will be explored during discussion around (the lack of) mobilisation later in this chapter, but tensions between these real-world application goals, and the academic environment of University X within which the project is situated are already emerging during interessement. 'It's a research University and your job is to publish papers… but really, it's important to the sponsor… to also have the technology be picked up by an outside company… So from the standpoint of [University X], the research,

the papers, the patents, those are what we're here for… [but] businesses… their whole focus is technology, but ours is Education', Lauren told me. '[Energynet] is like a prototype or a paradigm. That's what researchers do, they don't actually build real products', added Wujing. Similarly, Timothy said 'I'm a PhD student so I definitely have to be publishing papers', and Michael added 'I'm a PhD student, so everything I'm doing on this is geared towards getting publications'. Michael went on to explain:

> '[Energynet] is a research project, but there's also a lot of emphasis geared towards the practical end, and there's also this whole tech-2-market and business aspect. So for me I'm totally not sure what is more fundamental - research versus the applied part – that's something I've always had trouble totally understanding how everyone else views it… what's the goal here? Getting a practical thing? Or developing the more fundamental research questions behind it? For me personally, my goal, I like to address the fundamental parts first, and then obviously if it turns into something more practical and applied, that's great… It's been a little bit of a challenge for me because at times I want spend more time trying to come up with a more theoretical underpinning… but it's also good to have a practical problem to drive the framework' (Michael)

Emerging tensions between Energynet as 'fundamental research' or an 'applied project', as it has been framed by Marco (the token), is echoed by Lilian who thinks '…it's kind of a balance between hardcore fundamental research, and actually implementing these technologies in the field'. In this way, Marco's positioning of 'interdisciplinarity as application' during problematisation finds some resistance; his multiple, agentic identities as project manager and project researcher are again mutating, as his role as PhD student on the project, traditionally a role with less 'authority', is again performed to a greater extent. Despite the widespread enthusiasm around future technological applications within 'utopian' energy future visions, there are emerging interdisciplinary frictions between academia versus (interdisciplinary) 'applications' during the early stages of the

Energy project. The tensions continue as the narrative moves through to exploring enrolment within the project.

6.4 Enrolment (or, re-configuring inter/disciplinary relations through 'integration')

During this account of enrolment in the Energy project, the narrative continues to follow Marco and his encounters as his 'distributed' agency is constructed according to his (inter/disciplinary) relations with the Energynet actors (as they accept their roles in the emerging network, to differing extents). There is a project emphasis on engineering disciplines (within a 'quantifiable' inter/disciplinary spectrum), as sociology and other 'disciplinary inputs' resist enrolment according to the interdisciplinarities which were in construction during problematisation. There are emerging (interconnected) interdisciplinarity realities which coordinate in different ways as the project develops, as a multiplicity of actors enrol (or do not) into the project network; (inter)disciplinarities and their boundaries are conceptually (re)configured. The narrative will then focus on the (funder-driven) launch of a project laboratory at University X coordinated by Marco. I will explore the laboratory as a site of interdisciplinary (and disciplinary) multilateral negotiations and integrations; as technologies 'come together' in the lab, so do the human and non-human actors entangled with them, and thus emerge (inter)disciplinary (socio-material) assemblages.

6.4.1 An engineering-driven initiative, while 'other' disciplinary actors resist enrolment (within a 'quantifiable' disciplinary spectrum, according to the researchers)

The framing of the Energy project at problematisation proposed that, not only academic, industry and government stakeholders would work together in 'interdisciplinary' ways, but also that that different disciplinary areas should 'come together' *within* academia, in order to tackle the Energy challenges around which the grant proposal was based. The Energy project '…is interdisciplinary at first glance, it is supposed to be… This project was

defined as an interdisciplinary project' (Lauren). Following the first few months of the project, however, it is widely acknowledged by the researchers that the project is significantly 'engineering-driven'. 'In some sense it's interdisciplinary, but… I would say I don't see too much because almost everybody is coming from an engineering background', commented Gino, who is based at the National Laboratory and primarily works on simulations and 'validation' for the project. 'It's not sufficiently interdisciplinary. I would say it's an engineering project really, as far as I can tell', added Aman,[104] suggesting that his own conceptualisations of interdisciplinarity are underpinned by ideas around quantifiability and adequacy.

Furthermore, it was clear from the project outline at problematisation, as well as from its public-facing materials, including the project website, pamphlets and articles, that consideration of the eventual end-users of the technologies-in-development would be crucial. Marco, the human token, reinforced his own views on the need for this engagement, telling me that 'the home hub is the piece where you have to interact with the user, the consumer, at the end of the day, so we need to think about interactions with the consumer'. This in turn suggests a 'necessity', or at least an expectation, for social science disciplines to enrol within the project. Indeed, Barry, Born and Weszkalnys' (2008) interdisciplinary 'logic of innovation' is '…marked by the role of social science as a means to identifying potential users, desires or market for technoscientific innovations… for example, anthropologists might feed findings about emerging user preferences into the process or design [or] engineering' (Michael, 2017: 124). However, as the Energy project progressed, framed by Marco's preferences towards the end users' involvement, these (interdisciplinary) intentions at problematisation were not realised in practice. They were a 'big abstraction', according to Jack.

[104] Aman primarily works within his algorithms 'sub-group' on the Energy project and '…doesn't go to the big whole group meetings, because he's really only concerned with the control algorithms' (Timothy)

Janet, the project coordinator, identifies as a social scientist and thus presents as a 'spokesperson' in the project for social science and sociological disciplines. Indeed, Lauren's minutes for one meeting read *'Janet wanted to emphasise the social science factors: a user will be making a lot of choices which can be burdensome and yield user fatigue'*. 'I've tried to infuse a bit of social science [including] psychology, anthropology, sociology, and behavioural science… I just periodically review that literature and send [it] to the students… I've been trying to slowly over time build this repository of work related to their work', Janet told me. However, she went on to say, 'I don't know how much they read it… I don't necessarily have a deep intellectual input into the project'. 'I think right now Janet is more on the managing side, so maybe next step would bring some sociology knowledge into [the project]… sociology knowledge is necessary', said Wujing, while Michael added that 'I feel like there hasn't been as much for [Janet] to do on the social science end'. Gino likewise commented that:

> 'Still what I don't see completely… and I think is important, is the human aspect, which is what Janet is bringing to the project. I don't see in the model how the human being is included, and I want to see that because it [has] a big impact… the consumption of the appliance depends on the human lifestyle and you have to model that at some point!' (Gino)

'I want to learn how the human being can be included as part of the mathematical model', he added. This suggests his desire to 'learn about' other disciplines, reflecting Janet's observation that 'the field is changing: there are a lot more engineers interested in the human side'. This finding echoes broader literature investigating interdisciplinarity in the Energy field, and Wong (2016: 106) argues that, '…the social sciences have had little success in penetrating technical research on energy issues'. Pellegrino and Musy (2017: 3), discussing interdisciplinary energy research, similarly assert that "…energy issues concerning consumption are dominated by the 'hard sciences' and have mainly been addressed through techno-centric processes". Despite Marco's strong preferences towards

(interdisciplinary) engagement with the end-user during technological development within the Energy project, the corresponding disciplinary 'actors' of the social science disciplines - which, if enrolled themselves, may have worked towards enrolling the end-user – nonetheless resisted.

It is particularly interesting that though optimistic about the 'potential' for inclusion (or, enrolment) of the social sciences into the Energy project, Janet nevertheless appears to view social science as somehow of 'lower' priority within a perceived disciplinary hierarchy for the project: 'I think from now on we're going to go deeper into that [social science] arena, bring people into the meetings for presentations, when we don't have to do other technical work'. She added that:

> '[As we begin] developing interfaces like Priya's work with the mobile app then I become more intellectually critical, understanding the human sides of what we're doing as we move along in the algorithm development. It's time for that – we don't want to wait too late… I expect that I'll have deeper engagement, looking at user testing, or surveys that can supplement it' (Janet)

Priya, a software and mobile developer who, like Jack, doesn't see herself 'as a researcher', was brought onto the project for a brief time to build a prototype app to allow demonstrations of how the user might control their smart, connected appliances through the Energynet platform. But there are multilateral resistances to the social sciences in the Energy project; their difficulties enrolling into the project network (despite Janet's, their 'human spokespersons', efforts) act as a 'proxy' for the resistance of the (future) end user of Energynet to enrol. This will endure as the network struggles to mobilise, according to Marco's motivations and framings of interdisciplinarity, towards the end of this narrative.

Alongside a resistance by the sociological disciplines to enrol into the Energy project, despite their perceived 'necessity' for achieving the (interdisciplinary) project goals, it is notable that the researchers perceive other potential disciplinary inputs as 'lacking' within the project as well. For example, Aman told me that:

> ‘Clearly economics must play a part in the whole [project], but we’re not doing that… It’s very engineering oriented. But maybe over time it can be expanded - we’re trying. I think Timothy was planning to go more into the direction of economics. He’s taking a class and talking to a professor in economics about that. We’ll see how it goes. But I think it should, it needs to be’ (Aman)

Together with economics, the ‘computer sciences’, as a distinct disciplinary actor, do not fully enrol into the Energy project as it was suggested that they might at problematisation. Marco, the human token, in particular wants the team to ‘interact more with people from the Computer Science department… especially regarding visualisation [and] cybersecurity’. Jack adds that they should be ‘…bringing in outside contractors to do part of the work that we don’t have the speciality or the discipline to satisfy. An example of that is visualisations and animations and UI work’. During a few team meetings, according to my observations and Lauren’s minutes, there was a *‘plan to hire someone with visualisation/web experience to develop the interfaces and visual show’*. However, aside from Priya’s partial engagement, this did not transpire during my time in the field.

‘I think we lack more variety in disciplines’, said Jack, ‘…we could use designers, or other generalists in the sense that they could do a little bit of electrical engineering work or software work, or even talking to customers or project management’. Indeed, researchers’ concerns that the project ‘lacks enough’ different disciplinary inputs implies researcher conceptualisations of (the existence of) a ‘diversity’ of disciplines within a ‘spectrum’ of ‘quantifiable’ interdisciplinarity. For example, Lilian reinforced the widespread team observation that ‘most of the people working on [the Energy project] have engineering backgrounds’, adding, ‘…so I guess it’s more of like electrical engineering versus mechanical engineering – like different technical backgrounds rather than technical versus policy’. Notions around interdisciplinarity *within* the broader engineering field (within the project) were certainly discussed by a number of the researchers, further reflecting on a ‘diversity’ of project disciplines:

> ‘It’s not as diverse interdisciplinarity [compared to] what I’m used to …outside of me, perhaps, we have the range of the engineering disciplines, in large part… that goes from hardware guys to software guys, to guys like Marco that are interested in putting things together… so they all do different things and they come from slightly different disciplines but… they’re not as many different disciplines ‘ (Janet)

> ‘Because the scope of the project is so broad, there’s no way you can do this just with, for example, electrical engineers. You need guys from data analytics, guys from modelling… I’m pretty sure I would be able to do that but not in like a week, it [would] take me a long time! That’s the good side of having these different folks from different disciplines on the team. And again, because most of us our engineers we can relate - we know how hard it is for something to develop something or not’ (Marco)

Firstly, it must be noted here that Janet’s perception of Marco, the human token, as being able to ‘put things together’ - alongside his own estimation that, as an engineer, he has the competences to be able to, with time, undertake a variety of (disciplinary) functions within the Energy project - further suggests his relational and multiple agency. Secondly, Marco and Janet imply that they acknowledge a kind of ‘narrow’ interdisciplinarity on the project; that is, that the ‘interdisciplinary’ work ‘happens’ across and between disciplines within the broader (interdisciplinary) field of engineering.

Conceptualisations of ‘interdisciplinarity’, its role on the Energy project, and in particular, emphases on relationships between the ‘different disciplines’ within the engineering field, differed broadly between researchers during their interviews; rather than differing viewpoints, this suggests emerging, diverse (interdisciplinary) realities. For example, Timothy thinks ‘there isn’t really that big of a difference between electrical engineering and computer science: there’s a lot of crossover’, and for Daniel, ‘…the way electrical engineers describe things and the way mechanical engineers describe the same things is quite different’. But for Aman, on the other hand, ‘electrical engineering is too broad to be

a discipline'. Furthermore, in contrast to Gino's and Aman's comments, as noted above, that there is not 'too much' interdisciplinarity, and that the project is not 'sufficiently interdisciplinary', Lilian told me that 'I definitely think [Energynet] is interdisciplinary'.[105] Jack, Raj, Michael and Grant added that:

> 'Our project definitely covers more than one area… that's why I view it as interdisciplinary… there's some highly specific math, electrical engineering, mechanical engineering and software engineering. There's the psychological aspect of building a system that convinces ends users to use it and feel empowered… that's an area that's definitely outside my domain of expertise' (Jack)

> 'I think it's very interdisciplinary because… it ranges in terms of the areas from power systems, electronics, data science, embedded systems – these are all kind of engineering related but different areas – and computer science. Then it goes into this whole design of user interfaces, understanding how people think and make choices – some psychology – UI design, which is another totally different area. Then we work with folks from the Business school… the design has to reflect use cases that would favour a practical Business model where this technology could exist' (Raj)

> 'In [Energynet] there's hardware; power electronics; there's this embedded systems interface of the home hub which communicates with all these devices; and then there's all this algorithms and software laid on top of that to make it work. Those are often considered in isolation, at least in a research context. I think the fact that there's all those working pieces would make it interdisciplinary… And there are people with different skillsets. In a traditional research context, everyone would be in the same field, or they'd all be working on similar stuff, whereas in this project, if you talked to other people they would probably say their skillset is

[105] Additionally, Timothy told me that 'we have students from different schools [in University X]… rather than just from engineering', in contrast to other researchers' understandings of an 'engineering-driven' project, as described above.

different, and obviously whatever piece they're in, that would reflect that' (Michael)

> "[Energynet is] the galvanisation of set tools and methodologies from different areas of study, kind of galvanising around one focussed research topic… it manifests in [the Energy project], and especially with Raj and Janet: it's taking Raj's almost cold and sterile algorithms and optimisation schemes and data analytics, and Janet's consumer behaviour, human economics, human preference, that piece, and thinking, 'okay how do each of these fields with their tools and methods, what can they bear in this singular exercise of building a home energy optimisation world?'" (Grant)

Firstly, these lists of disciplinary 'inputs' (which 'work together'), as well as different technological components (organised around different 'disciplinary groups') suggest a perceived 'quantifiability' (and to some extent, discrete nature) of interdisciplinary for researchers within the project. Secondly, and perhaps more strikingly, it is noticeable that these 'lists' contain some disciplines which it has already been established that other researchers did *not* view as engaged in the Energy project, such as computer science and 'the psychological aspect' or 'consumer behaviour'. These competing, and overlapping, emerging interdisciplinary realities (including whether or not the project is 'interdisciplinary' for different researchers) are partially constructed by researcher differences in how a discipline, and a 'spectrum' of interdisciplinarity might be, and is, conceptualised:

> "If one means by 'discipline' something narrow like control theory, data science – if you think of these are separate disciplines - then you can argue that this [project] is interdisciplinary. But to me, it's too close. I mean, I'm not sure that I would call that interdisciplinary… How narrow is a discipline, right? I think [interdisciplinarity] is more of something that is driven by the problem, and you can't really solve it yourself because you don't have the skillset, so you need to get

somebody who is not in your [field]. If you collaborate with another mathematician whose area is a little bit different, I don't think that's interdisciplinary - that's just disciplinary. It has to be a little far away from [each other]' (Aman)

Aman, while defining interdisciplinarity in ways which could be compared to Barry and Born's (2013) 'logic of accountability', further reinforces many Energynet researchers' perceptions of a (quantifiable) 'spectrum' of disciplines. There are thus emerging (interconnected) interdisciplinarity realities within the Energy project which coordinate in a multiplicity of ways as the project develops, as a multiplicity of (disciplinary) actors enrol (or do not) into the fluctuating project network. As the narrative has laid out so far, Marco 'sits' embedded within, shaping and shaped by, this complex network of relations, through which he – and indeed the other actors, including the researchers and technologies-in-development – construct his (interdisciplinary, agentic) identity during enrolment. Technologies-in-development 'speak for' academic disciplines, (inter)disciplinarities and their boundaries are conceptually (re)configured, and agency is fostered through complex interrelationships as the project network enrols a prominent new actor: the laboratory at University X.

6.4.2 The Lab Launch at University X (or, a space for actors to negotiate their practices, disciplinarities and interdisciplinarities)

(Interdisciplinary) 'integrations' between actors, including human researchers and technologies-in-development, are partially driven by the funder requirement for 'communication' between (disciplinary) technological components: 'for the next milestone… it's a basic integration between all the pieces… doing basic communication', Marco told me. '[We now have] integration meetings because all of these different components… need to become integrated… A lot of the upcoming milestones have to do with merging these different pieces together', said Lilian. One Q5 milestone in particular was to 'demonstrate [dimming] fuse integrated functionality with home hub', and Raj

explains that 'we are forced by [the funders] at the end to deliver a single platform' (according to 'program element 5'), adding that 'here you have to build a single solution… [this makes it] interdisciplinary… pulled into one platform'. Building an Energynet laboratory at University X offered a physical space for the technologies-in-development to materially come together for communication and integration in this way. 'The lab is where we're going to showcase the entire [Energynet] platform… It's a milestone, a requirement from the Department of Energy' said Marco.[106] The 'showcase lab', as it is often referred to by Marco in team meetings, is indeed framed by the project's public-facing literature as a space for integration of the different technologies-in-development, into one platform, 'Energynet'. The Energy project website and pamphlet, under the title 'Integration and Validation', explains:

> '[Energynet] researchers will develop and test the fully integrated end-to-end system in [the lab]… [It] is in the engineering quad of [University X's] main campus… [and] will use hardware-in-the-loop simulation, includ[ing] physical energy assets—solar power generators, energy storage devices and home appliances—using [dimming] fuses and home hubs. They will also use virtual, heterogeneous homes. The [cloud coordination device], in turn, will operate within a software platform simulating the broader grid, load forecasts and economic data necessary for system optimisation in real time… Researchers can control the virtual grid to test multiple and rapidly shifting scenarios'

Figures 42 – 44 show the proposed laboratory 'layouts' graphics, pre-construction. They were put together by Jack and Marco, and illustrate how it was planned that the technologies-in-development would integrate physically within the space of the new lab:

[106] 'If we can somehow at least show this works for our lab, we can… show that what we're doing can make an impact to some extent. We want to give some insights… that the practitioners or the utilities or the future distribution system operators can see. This is a tiny, tiny prototype [but] we can probably make that work in the real world' (Wujing)

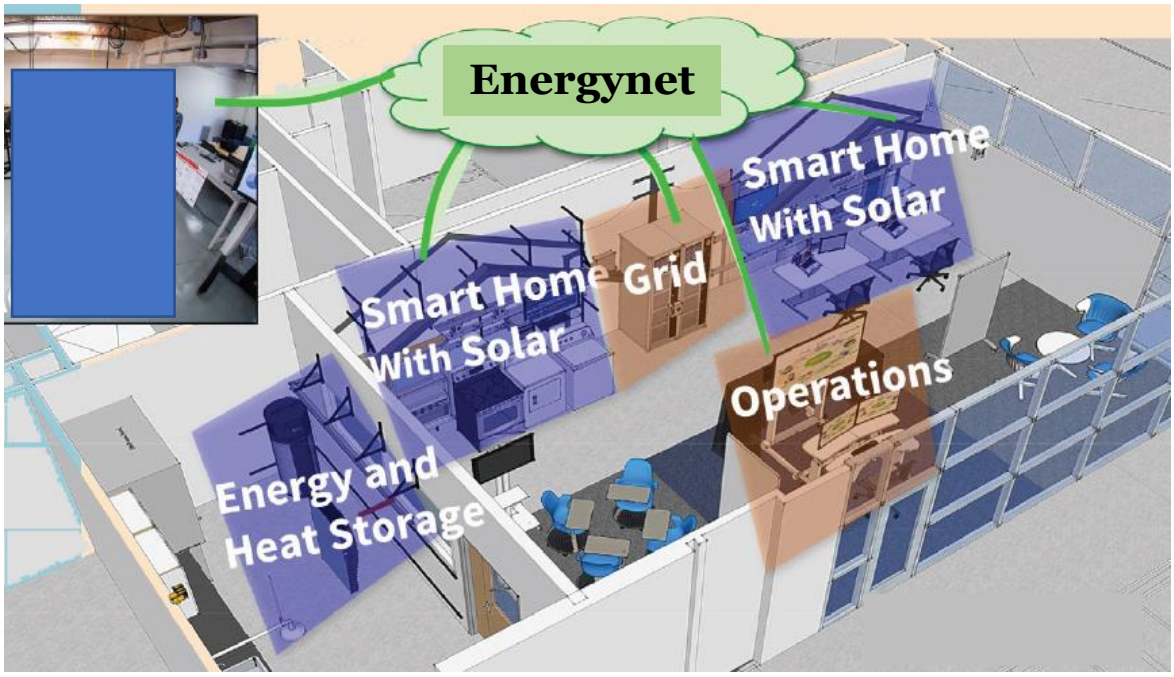


Figure 42. Proposed University X laboratory layout from the Energynet pamphlet (adapted)



Figure 43. University X laboratory 'mock-up' from a site visit presentation in Q3



Figure 44. University X laboratory 'mock-up' from a site visit presentation in Q3 (2)

A Google doc was created by Lauren, available for the Energynet team to view, to track the progress of the laboratory completion, on a timeline ending with the designated day of the 'lab launch', as it was referred to by the researchers. As agreed in a previous team meeting, and according to Lauren's meeting minutes 'action items', *'Marco will create a step-by-step timeline for the lab completion'* – and this timeline formed the basis for the Google doc. During each team meeting, Marco presented laboratory construction 'progress updates' (with some occasional inputs from Jack and other team members) to the Energy project team. 'It's difficult to find a guy like Marco who can set up a lab, also do the research, and [build] software…', commented Raj to me following one meeting. During an interview after the 'lab launch', Marco recognised his pivotal role in developing, constructing and enrolling the laboratory at University X:

> '[I was] driving the lab, [deciding] what would be a good fit for the lab, what would be good demos and setups that we could do - that was something that I contributed to a lot [and] helped change the direction' (Marco)

'Marco and Jack were there all weekend and all night' before the laboratory opening, Janet told me. The way in which Marco is positioned, and positions himself, within the

'run-up' to the laboratory opening is significant. His creation of the timeline, his updates to the other researchers regarding the lab construction progress, and his decisions regarding its functions and contents - particularly when assembled alongside his existing, multiple roles as software developer and project researcher – construct and augment his distributed, agentic identity, and his developing 'power' in the network.

The laboratory opening was combined with a 'site visit' for the project. Quarterly site visits, when representatives from the Department of Energy funding body visit University X for 1 -2 hours, primarily for progress updates, typically consisted of PowerPoint presentations around each of the technological components (according to the project 'tasks' and 'milestones'), delivered by those developing each component, respectively. 'Those have been a really valuable experience of actually learning what other people have been working on [and] get good feedback [on my work]', said Lilian of the site visits. I observed four quarterly site visits held on campus or at the nearby government-owned national laboratory, and the most significant of these was the opening of the new project laboratory in the Environment and Energy Building on the University X campus.[107] The 'lab launch' site visit began with demos of different components within the laboratory. Sixteen people were present in the lab during the launch demos, including two representatives from the Department of Energy funding arm. Raj introduced the lab as a 'student-driven effort' to the representatives from the funding body, and Jack then went first demoing 'home number one simulation'. Figures 45 – 47 show various aspects of the University X laboratory during these demos.

[107] In a team meeting, Raj says he wants the lab to 'look five years into the future'.

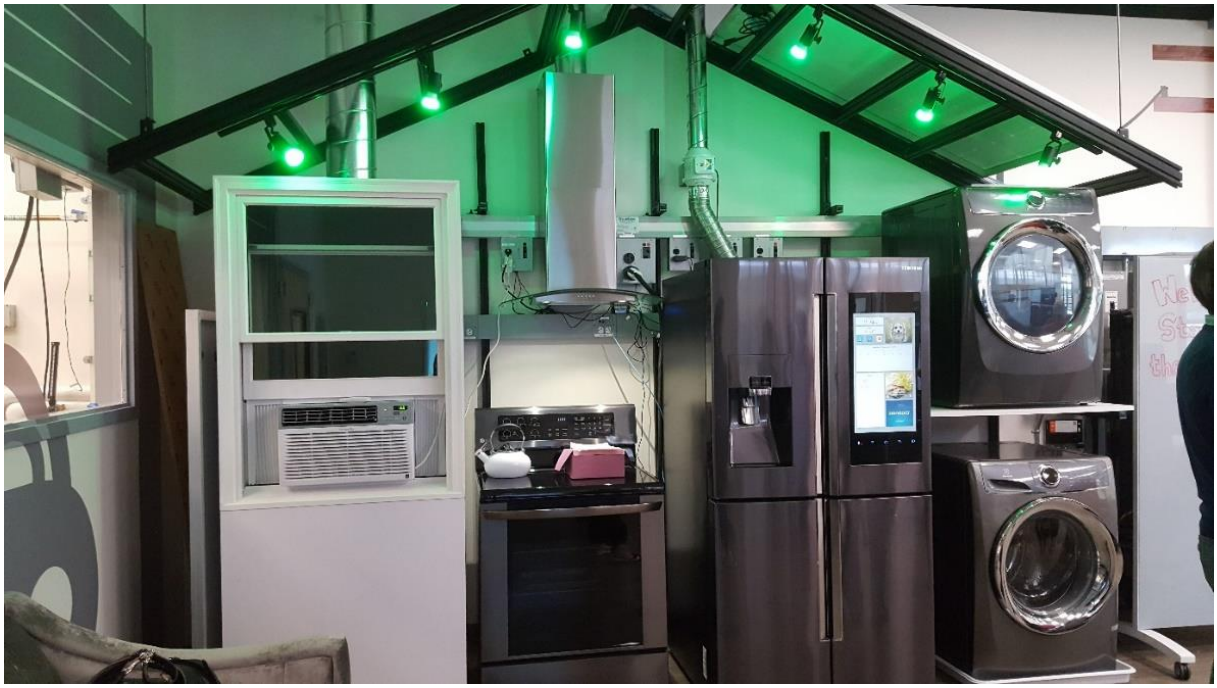


Figure 45. The household appliances in the laboratory at University X



Figure 46. The project funders, and Energynet team members, watch as a simulation demo is given during the lab launch at University X

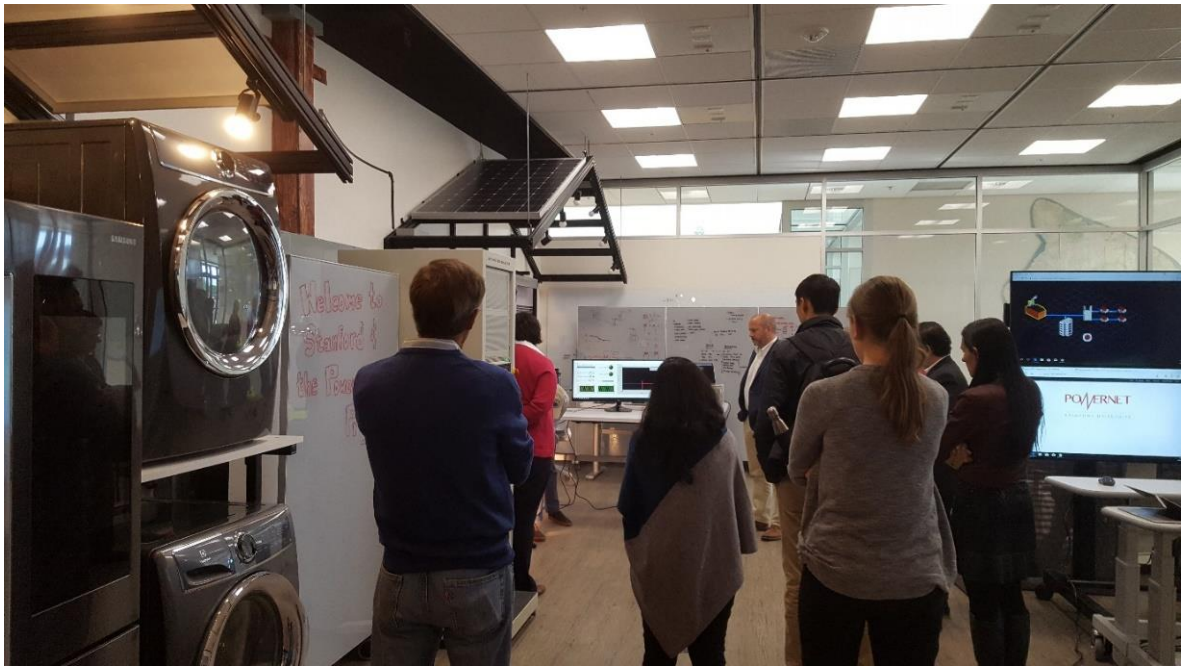


Figure 47. The project funders, and Energynet team members, watch as a simulation demo is given during the lab launch at University X (2)

Furthermore, a promotional video about the University X laboratory explains how two homes are modelled in the Energynet lab. As per the website and pamphlet description above, the first home model is comprised of a full set of electric appliances including an electric storage unit and water heater. The second home *simulates* various appliances, and both modelled homes are connected to a grid, represented by a grid emulator, simulating exchanges of power with the 'outside world'.

The laboratory is a physical space for the technologies developed within the Energy project to 'interact' in some of the ways laid out in the grant proposal at problematisation, and a space for (interdisciplinary) negotiations between humans and non-humans, most notably the technologies-in-development and their respective development teams. 'Now people feel that they have a place to make [their work] very concrete… what it means for home hub to work with the data analytics and the cloud. It's a real scenario where things are happening, I think it makes a big difference', commented Raj after the lab launch. As the technologies were drawn together, they simultaneously brought together their (disciplinary) development groups, consisting of both human researchers and other non-

humans. Shifting, collaborative socio-material practices and interdisciplinary (and disciplinary), multilateral negotiations materialised in the laboratory, as new (inter)disciplinary (socio-material) assemblages emerged. For instance, Raj and Timothy explained that:

> 'Different sub-groups have to interact because the solution has to be installed in the lab and made to work there. So the fuse group and then the home hub group had to interact so the fuse can eventually work with the home hub…' (Raj)

> 'I had to combine my algorithms with all of the hardware in the lab… My work is mathematical, and then the work that Jack and Marco were doing was more like software engineering. So it's not extremely different, but it's still sort of different' (Timothy)

These descriptions suggest how the technologies 'took the lead' in the emerging interdisciplinary collaborations, and thus how heterogeneous actors and practices were subsequently enrolled by the lab into the interdisciplinary project network. Indeed, Marco markedly told me that:

> 'Interdisciplinarity will happen when the technology asks for it' (Marco)

If the governmental funding body drives (in part) 'integration' between technologies-in-development, then the technologies-in-development drive (in part) interdisciplinary enrolments of a wide variety of (inter/disciplinary) actors. 'The real interdisciplinary parts come in connecting the components', Timothy told me. Raj elaborates upon the changing practices, following the launch of the laboratory, describing a particular instance of (interdisciplinary) negotiations between 'sub-groups' within the lab, situated around Marco and his position in the new 'collaboration space':

> "I asked [Lilian] to go and work with Marco to set up the lab… That turned out to kind of inspire her thinking about how appliances work, how this whole data thing is working with the fuse. I [had] said, 'we need to find a quick way of setting up these

> simulations', and my intuition was we should use the data. But since she had seen the fuse in the lab, and the methods in the fuse, she said, 'oh yeh I know these methods, I can apply it here and to the simulator'. So suddenly she could see [what to do] because there was an attempt to connect the fuse to the home hub through Marco. So Marco was the connector… [and] she observed… and now she's connecting that whole thing to the simulation" (Raj)

Firstly, through his enrolment of the lab, and the lab's enrolment of other actors, Marco's, interdisciplinary, relational and multiple agency is constructed, and his – and others' – interdisciplinarities are performed. His agency is distributed across the (interdisciplinary) assemblages emerging through the laboratory. Secondly, this shows how interdisciplinarities-in-the-making are brought about through the enrolment of the lab (and its own status as an enroller), as 'disciplinary' practices come together. Timothy and Jack add that:

> 'When I have to combine with Michael's side of things, now I have to consider his solution as well. We might have to change the problem a little bit so it works with his solution better' (Timothy)

> "When I'm collaborating with someone and taking their algorithm and running it under our architecture and making sure everything's good to go, I'm not really saying, 'oh this part of the algorithm could be a little bit better', I'm not touching any of that, I'm just saying things like, 'well when you set it up, maybe do this a little bit differently'… It's putting process and boundaries around the way they do things, and not just being prescriptive…" (Jack)

In these ways, the laboratory at University X becomes a site of interdisciplinary (and disciplinary), multilateral negotiations, where (interconnected) interdisciplinarity realities coordinate in different ways. As technological assemblages 'came together' for and in the laboratory, so did the human and non-human actors entangled with them. Marco was the 'coordinator' for the launch, and through his enrolment of the lab, and the lab's enrolment

of others, his relational agency was shaped, and his interdisciplinarities were performed. 'Human powers increasingly derive from the complex interconnections of humans with material objects' argues Urry (2000: 14), and Marco derives some of his 'power' and agency from the laboratory and its technologies-in-development. 'The agency of nonhumans enables the agency of humans which enables the agency of nonhumans and so on' (Michael, 2017: 69). From this moment in the Energy project, (inter/disciplinary) practices are mediated by the laboratory. It is through the construction, materiality and enrolment of this laboratory that (existing and new) heterogeneous actors were drawn together and enrolled in the project network (in interdisciplinary ways). But tensions arise as attempts are made to extend the network into other (inter/disciplinary) domains, and the final section of the narrative, (lack of) mobilisation, explores these tensions.

6.5 (Lack of) mobilisation

This project network does not 'reach' the fourth and final moment of translation, mobilisation. As I left the field, technologies developed through the Energy project 'struggled' to leave the University X environment. Whilst some situated interdisciplinarities were performed, the network was not durable or stabilised enough for representation in industry, 'failing' to enact part of the project 'vision', as it had been defined at problematisation. This was despite the potential for representation through Marco's, and the new project laboratory's, emerging (interdisciplinary) agencies. The narrative of this section will explore a breakdown of the Energy project network in mobilising (interdisciplinary) applications of the technologies in the 'real-world', through 'tech-to-market' commercialisation. This is to do with interdisciplinarity in a university environment, and implications for the movement of technologies developed in an academic locale across (disciplinary) boundaries into a commercial setting. Factors that undermined mobilisation include the lack of interessement and enrolment of the end-user, due to a lack of enrolment by certain disciplinary actors, including the social sciences and business.

6.5.1 (Interdisciplinary) breakdowns in the mobilisation of the (interdisciplinary) 'vision': difficulties with commercialisation for 'real-world' application

It was established during the problematisation and interessement sections of this narrative how 'visions' of a 'utopian' Energy future, *potentially* achieved through 'real-world' applications of the technologies-in-development, drew actors towards the framing of the Energy project:

> 'A lot of the [Energy] technology developed in the past ignores the business model completely – they don't care if it's going to become some reality or not… But here what we said is, what are the realistic cases that people may want to use that could derive on somebody profiting from this platform… and then on that question, many of the things we found to be important, profitable and desirable, were things we were not first thinking about' (Raj)

Despite some interdisciplinary resistances, (disciplinary) technologies were drawn together in the University X laboratory towards this 'vision', partially through Marco's distributed, interdisciplinary agency. Indeed, 'now that the lab is basically finished, we need to run a lot more demos, we need to interact with customers, investors and program directors… as opposed to just developing the technology [and] doing the research', Jack told me. '[We need to] take this from a research project to having a commercially viable product', he added, as Gino agreed that 'the transference of technologies to industry is very important' for 'achieving' the project's goals.

Furthermore, in line with his 'commercially-driven' interests,[108] and constantly mutating agentic identity, Marco began to move away from continuing technological development in the lab, and towards leading the 'tech-to-market' efforts for the project; that is,

[108] It is important to note that there are still fluctuating tensions between Energynet as 'fundamental research' or an 'applied project', as laid out in the interessement section of this chapter: 'Because of the nature of this being a research project… whether or not this is successful in the market says nothing about whether this project was successful' (Jack)

commercialisation of the Energynet platform, now housed within the University X laboratory, in accordance with 'program element 7'. 'Now I'm also dealing with the tech-to-market piece… I'm interested in tech-to-market, understanding the environment we're developing the technology for, but it's taken a lot of my time from the development… and from my PhD', Marco told me. The laboratory began to interesse new (commercial) actors towards the Energy project, through industry visits and technological demonstrations, and Lauren told me that when '…they set the lab up and we were opening it up to new people, that was a very exciting milestone… Most recently, somebody that may be a key element of our tech-to-market research [was given a lab demo]'. However, despite Marco's work with and alongside the laboratory, their distributed and relational agencies working to interesse and enrol industry actors into the Energy project, there were nevertheless significant resistances:

> "It's applicability in the market, in the real world right now is a bit divergent than what I had originally thought. When I first joined the team I thought, 'oh I can see exactly how this can be implemented right away, we've just got to come up with a good solution and everyone's going to love it and people will adopt it right away'. But the more I learn… it seems like the potential is still there, but we're farther away than I had originally anticipated, or wanted to be…" (Jack)

> "I think the expectations were really high before the project started, I guess it was more because of a lack of knowledge in the market. I mean I could clearly see the potential but the more I go into the Energy environment, the more I feel that it's going to be really hard. It's tough, there's a lot of policy [and] legislations… From an engineering perspective, I mean you don't care about it, you just think, 'that's an awesome technology, let's do it'… So that's why I think the excitement was too high because of my lack of knowledge of the entire environment." (Marco)

Whilst both Marco and Jack recognise a *potential* for the technologies to be applied in the world, they are concerned about their interactions within the wider complexities of the

Energy industry (considering people, frameworks, economics, and so on). Pellegrino and Musy (2017: 4) argue that Energy research '…requires an interdisciplinary perspective as it simultaneously encompasses physical, technical, spatial, socio-economic and human aspects. Until quite recently, researchers in the engineering sciences did not see the urban environment, as a whole, as an object of research', and Marco's comment in particular suggests an absence of cognizance around the (interdisciplinary) multi-faceted Energy market, itself a heterogeneous socio-material assemblage, from an engineer's ontological standpoint. Indeed, Daniel, who considers interdisciplinarity as inherently 'good practice', commented that '[engineers] don't want to figure out how to monetise what they're doing, they want to figure out how to do what they're doing optimally'. Lauren added that '[Energynet] was defined with a tech-2-market part which isn't what an electrical engineering student [knows]', going on to the elaborate that '…this is where you bring in the School of Business. And definitely if you get involved with the homeowners then you need somebody like Janet with the sociology to really understand all the things that are required for that'. However, as was established during the narrative of enrolment, there was a resistance by the sociological disciplines to enrol into the 'engineering-driven' Energy project, despite their perceived necessity (on the part of the project researchers) for achieving the 'interdisciplinary' project goals. These resistances of social science disciplines to enrol into the project network undermined mobilisation; in-turn the stakeholders external to the project 'represented' by the disciplines, including the end-users, struggled to interesse and enrol (thereby, in part preventing the Energy project technologies from 'mobilising' into a commercial environment).

Alongside resistances by the social sciences, a lack of enrolment by 'business', conceptualised by the team as an (inter)disciplinary field, also undermined mobilisation. As shown in figure 39, Grant was the only team member on the Energy project who identified solely as a 'spokesperson' for the (inter)disciplinary domain of business. Grant, the joint MBA/MS student, however, began to un-enrol from the project following the 'lab launch' as he was graduating from and thus leaving University X. Marco commented that:

> ‘I would love to have Grant be more engaged in the project, because I think it’s really, really important; it doesn’t make sense if we develop this nice technology, and we don’t have a business plan of how we can take to market… We have to have that mindset of what are the market needs, which I don’t think we have… We don’t have a core team for the business… we never had a core team that we can rely on like we have for home hub. I think that’s because maybe Raj or the co-PIs don’t think that’s important, that’s what I feel.’ (Marco)

Firstly, Marco’s final comment echoes Raj’s remark that ‘…program element 7: …tech-to-market, was demanded by [the funders]’, suggesting that it was primarily driven by what was perceived as an ‘external impetus’. Secondly, it is notable that Marco sees inadequate engagements with ‘commercialisation’ on the project; he thinks this is due to their ‘lack’ of a disciplinary ‘cluster’ within the project working on it. Lauren added that, “…the big ‘tech-to-market’ part [is] a little bit floundering right now”. Her minutes from a team meeting following the ‘lab launch’ reflected this, reading that *‘…the group is a little concerned because we need an update for the tech-to-market piece’*; this view was indeed held by a number of team members. These meeting minutes also read that:

> *‘Grant asked if Marco had a specific objective, such as looking for more industry partners that may want to take over part of what we are developing or talking to regulators in some of the areas where we are struggling like the aggregation of homes and privacy issues. Marco agreed all those areas would be great, but mostly we need to develop T2M’.*

As has been presented throughout the narrative of this chapter, it is clear that Marco in particular is concerned with accomplishing the project’s objectives for commercialising Energynet. Nevertheless, his framing of ‘interdisciplinarity as application’, was met with significant resistance as it worked towards mobilising ‘commercialisation’, that is, mobilising the (interdisciplinary) ‘vision’ for the Energy project technologies:

> “The more I talk with the industry folks, and see the other applications, I think we could be doing a lot more… For the market, I think we are ten years behind… I’ve been to most of the conversations [Grant’s] had with industry folks. He invites me,

> and says, 'please come because you have a better perspective, an overview of the entire project'.... I think the milestones that we have do not necessarily meet those requirements from the industry... I also try to engage more with start-up companies... I don't know if there are a lot of people willing to go and pursue that connection with them" (Marco)

Marco has identified what he perceives as miscalculations laid out by the project proposal. The problematisation (alongside interessement, and to some extent, enrolment) did not frame the project for 'successful' mobilisation (through Marco's framing of interdisciplinarity as commercial application). 'There needs to be much more focus on how we actually make [this] happen in the real world', added Aman. The network was not stabilised enough for representation in industry, 'failing' to enact part of the project 'vision' (as it had been defined at problematisation), despite the potential for representation through Marco's, and the new project laboratory's, emerging (interdisciplinary) agencies.

Nevertheless, Marco and Grant both recognise potential for commercialising individual (disciplinary) technological components, as they were developed (in their 'modules') before being drawn together within the (interdisciplinary) Energynet platform:

> 'I think we have a lot of pieces that we can bring to the market even if... the [Energynet] platform won't work; we still have different pieces of the project that can definitely become products... You can commercialise the fuse – there's a lot of companies interested in that – you can commercialise the home hub. The algorithms running on the cloud you can also sell to utilities' (Marco)

> "In some of our discussions with industry stakeholders, they [said] 'you seem like you have discrete technologies, but then there's this behemoth [Energynet] thing'. I think for the average industrial partner, the behemoth is quite intimidating, because [they] might not need this hardware piece, maybe [they] only do algorithms... It would be great if there were some more discrete elements that

> could be commercialised outside of the whole… The fuse itself is nicely tangible and nicely self-defined, nor does it necessarily have to fit within the larger architecture, for example" (Grant)

Indeed, Raj told me that '…for commercialisation… we are patenting some of the algorithms, some of the hardware, the fuse hardware… [and] our forecasting was of interest to several companies'. Interestingly, this might suggest capacity for some 'disciplinary' mobilisations, despite 'inter/disciplinary' breakdowns in the mobilisation of the (interdisciplinary) 'vision' within this Energy project network. Engagement of (human) 'business' actors within the network, including Grant (the MBA student) and Jack ('from industry'), might contribute to some 'disciplinary' mobilisations. Nevertheless, there has been a breakdown in mobilising 'interdisciplinary' applications of the technologies in the 'real-world', through 'tech-to-market' commercialisation.

6.5.2 Interdisciplinarity in a University environment: implications for technology transfer

Klevorick et al. (1995) argue that graduate students are one of the 'channels' by which knowledge 'flows' between university to industry. 'The graduate student embodies the expertise that makes science alienable and high-technology product and process development possible…. [The] graduate student… understands that the state, the corporation, and the academic research lab are fused together…', contend Slaughter et al. (2002: 308). As the narrative has shown, Marco's, a graduate student, agentic identity has been in-part constructed by his 'situatedness' at interdisciplinary boundaries, not only between academic disciplines (as delineated by University X), but also between academia and industry. However, working in 'interdisciplinary' ways might have (counterintuitively) undermined Marco's agency in mobilising the Energy project and its technologies. For example, Daniel told me that 'interdisciplinary stuff… is essentially a distraction' for graduate students:

> 'I just don't think we run graduate research in a way that really lends itself to interdisciplinary research… It's very stove-piped, tends to look down on anything that's not within its own area' (Daniel)

Indeed, it is also important to note, as shown through figure 39, the number of graduate students engaged in the Energy project, and the potential implications for the project of Daniel's observations in light of this.[109] 'The churn of students through the project… can be detrimental overall. Mostly because the time that's spent to transfer knowledge, and then the eventual loss if that falls through', added Jack. Despite this, Marco told me that '…when you're at the level of PhD, especially here at [University X], I think there's no distinction between departments'. Either way, Pellegrino and Musy (2017: 8) argue that 'Universities need to play a major role in supporting interdisciplinary energy researchers, especially in early and mid-career'. Marco's status as a graduate student researcher, and the project's situation within a university environment, undermine the mobilisation of the technologies, developed by the Energy project, across a (disciplinary) boundary into industry. Alongside the 'lack' of interessement and enrolment of the end-user, due to resistances against enrolment by certain disciplinary actors including the social sciences and business, the position of the ('interdisciplinary') Energy project within a university, University X, impedes mobilisation. The potential for Marco's interdisciplinary identity, his emphasis on the importance of application of the Energy project technologies in the 'real-world', to represent the network in industry, could not be accomplished.

6.5.3 Summary

Interdisciplinary and disciplinary realities have been performed and enacted through the practices of the Energy project, and following a token, Marco, has helped to bring situated (inter)disciplinarities in the project network to the fore. This final findings chapter has described how a *human* token's, Marco's, agency is constructed through

[109] This is markedly different from the other two case studies in this thesis.

(interdisciplinary) relations. His relational, multiple agentic identity is distributed across actors within the unfolding socio-material assemblages of the Energy project, as it moves through technological research and development practices. Following the emergence of a project grant proposal, formulated through (interdisciplinary) connections with industry and government, actors were drawn towards the Energy project through interessement. Marco's status as an 'interdisciplinary knowing location' was constructed through relations within the project as (disciplinary) technological development progressed. I described how shared 'visions' of a 'utopian' energy future, potentially achieved through 'real-world' applications of the technologies-in-development, interessed actors. As the narrative moved through enrolment, I discussed how sociology and others 'disciplinary inputs' resisted enrolment, as a new project laboratory at University X became a site of (inter)disciplinary multilateral negotiations and integrations. McGregor (2004: 367) concludes (from her study of teachers in science education) that '…knowing is a relational effect where pedagogy is a collective accomplishment and learning a situated activity'; here, *interdisciplinary* knowing is relational effect where *interdisciplinarity* is a collective accomplishment and *being interdisciplinary* a situated activity. Finally, I examined how this particular project network did not 'reach' the final moment of translation, mobilisation, as technologies developed through the Energy project 'struggled' to leave the university environment. The (interdisciplinary) network was not stabilised enough for representation in industry, 'failing' to enact part of the project 'vision', despite the potential for representation through Marco's, and the new project laboratory's, emerging (interdisciplinary) agencies. Wong (2016: 109) argues that 'it is fair to say that the future of energy research is bound on a trajectory of interdisciplinary assembly… Disciplinary loyalties will have to be abandoned or at least reconceptualised…', and in the following chapter, I will discuss how emerging (interconnected) interdisciplinarity realities and (re)conceptualisations of (inter)disciplinary boundaries have been enacted in practice across a *multiplicity* of (inter)disciplines - Energy, the Digital Humanities, and Medical Robotics - through the three case studies presented in this thesis.

CHAPTER 7: DISCUSSION

7.1 Introduction

This thesis thus far has explored how emerging (interconnected) interdisciplinarity realities and (re)conceptualisations of interdisciplinarity have been enacted in practice across different (inter)disciplines through empirical work.[110] This chapter discusses how the findings and analyses from the previous three chapters relate and contribute to wider literature, further serving to (un)settle matters of technologically-mediated interdisciplinarity, in answering the study's research question: 'How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?'.[111] In the discussion, the study's three cases - each having examined how interdisciplinary, heterogeneous research teams (both human and non-human) develop new technologies - will be woven together. This discussion will not only compare findings across the three cases, but will also consider conceptual and methodological points which emerged from the findings, primarily around how ANT assisted *and* resisted my efforts to explore the 'textures' of interdisciplinarity. Section 7.2 of the discussion will further 'open up' the practices of technologically-mediated interdisciplinarity. Exploring the 'myths and dichotomies of interdisciplinarity' which were laid out during the literature review (Graff, 2015: 10),[112] the narrative of this section flows across five (inter-related) sections; each part contributes in different ways to (re)conceptualisations of the nature and (shifting) complexities of technologically-

[110] Broadly, I use (inter)disciplinary to signal both interdisciplinarity and disciplinarity, and inter/disciplinarity to signify the fluidity between them. 'Interdisciplinary', in quote marks, in often used to reflect the researchers' or documents' views of the projects and practices. This choice reflects my 're-presentation' of the interdisciplinarities-in-construction.
[111] It is key to note that, as identified in the literature review, there is only a very small and nascent area of study which examines interdisciplinarity through a constructivist lens. Therefore, due to space and relevancy, this chapter will *primarily* consider this relevant literature.
[112] The idea of interdisciplinary 'dichotomies' has now been found to reflect many of the researchers' 'personal' views, as well as that of the literature (see 'Emergent' section in this chapter).

mediated interdisciplinarity. This first section will explore how the following five themes were evident across the cases, suggesting that interdisciplinarity 'is':

a. Situated: mediated and 'embodied'
b. Emergent (inter/disciplinarity)
c. Irreducible to antecedent 'parts'
d. (Made of) relational tensions (and multiplicities)
e. Distributed

'Getting to know' the complex 'matter' of interdisciplinarity

There have been latent, at times palpable, tensions running through the three case study Findings chapters of this thesis, and it is during this discussion that these are further brought into focus. The theoretical framing of this investigation, drawing heavily from Actor-Network Theory (ANT), brings with it an appeal *not* to 'simplify' phenomena. But if these practices have indeed been (partially) enacted through their (re)presentations in the last three chapters, 'opening up' the moving complexities of technologically-mediated interdisciplinarity, then how can they be 'knowable' or 'tangible' enough to be adequately discussed within the 'static' confines of a Discussion chapter within a D.Phil thesis? In other words, how can we accommodate the sprawling complexities of interdisciplinarity, through inevitably 'simplifying' written accounts? How can we 'know' technologically-mediated interdisciplinarity? It is important to note that some level of 'reduction' of the findings must take place here in order for them to be adequately situated within the broader literature. This has been a significant challenge in the structuring and writing of this chapter, and as such these tensions not only continue to thrive in this work but begin to form a significant 'discovery' themselves. During the writing and analysis of the Findings chapters in particular, grappling with this became an unexpectedly important aspect of the thesis, and now forms an interesting reassertion of the literature review discussion on the nature of existing definitions of interdisciplinarity as 'simplifications' of

the phenomenon. This will be attended to towards the end of this chapter in section 7.3, "How can we 'get to know' the 'matter' of interdisciplinarity?"

7.2 Socio-material practices of technologically-mediated interdisciplinarity are:...

7.2.1 Situated: mediated and 'embodied'

The findings of this study suggest that interdisciplinary socio-material research practices are situated; that is, their nature is contingent on their 'location' within the ways in which (disciplinary) cultures and 'traditions' of knowledge production are drawn together within a particular research project, as well as on the various other social and material specificities through which they are constructed. The 'situatedness' of interdisciplinarity in projects developing new technologies at University X was illuminated through the 'rich descriptions' of the previous three Findings chapters. In this way, the study indicates that interdisciplinarity does not exist outside of its enactment. As such, when funding agencies and other actors talk about it conceptually, 'it' doesn't exist – and it exists differently, it is a different 'thing', each time it is constructed by a research project. It is 'slippery' as it is performed in each project, with no 'fixed' form (Law and Lien, 2012). Interdisciplinary knowledge practices are local, and 'being interdisciplinary' is situated.

Indeed, situated interdisciplinarities have been enacted during different moments within the cases of this thesis, 'through specific materialising processes in particular situations' (Fenwick and Edwards, 2018: 9). I have built upon my argument in the literature review, supporting Donaldson, Ward and Bradley (2010: 1535) who champion a 'move away from the various justifications and conventions that seek to pin down the essential reality of interdisciplinarity and towards a position in which there is no reality to interdisciplinary research other than that which is made in practice'. These findings are also corroborated by the work of Carp (2001: 71) who argues that all 'knowledge formations' (the term he uses for 'disciplines' and 'inter-disciplines') are 'partial and situated', rather than being 'privileged site[s] of especially valid knowing'.

Situated (inter)disciplinarities-in-the-making were brought into the foreground in this thesis by following three tokens through processes towards translation, across three cases, and this variously unpacked different nuances around the 'situatedness' of technologically-mediated interdisciplinarity. These 'situations' can best be explained through two more 'tangible' themes: interdisciplinarity as mediated, and interdisciplinarity as embodied.

Mediated (by tokens and other objects)

The 'situated' nature of technologically-mediated interdisciplinarity in this study is evidenced by the ways in which the phenomenon was mediated by objects – or, 'practice negotiating artefacts' (Jordan and Rimpiläinen, 2010: 3) - across the cases in different ways. For example, the steerable needle token in the Medical Robotics project (CS1) was shown to mediate interdisciplinary interactions across human and non-human actors as it moved between traditionally 'engineering' and 'medical' spaces within University X, entangling the (inter)disciplines of robotics (embedded within engineering) and medicine. One particular instance of this was described when the size of the needle was contested by a radiologist and an engineer. Through this mediation, situated interdisciplinary practices were enacted.

Similarly, the second case token (CS2), the concept of 'encoding a humanities epistemology' into a technology**,** (constructed and) mediated the project's situated interdisciplinarity. This happened not only as it actively problematised disciplinary knowledge practices in an explicit attempt to mobilise an interdisciplinarity, but also as actors, including humanists and engineers, 'bought into' the (interdisciplinary) aspirations behind the concept, with some theoretical understanding. Another object in this case (CS2), one of Alessandra's diagrams (as material research practice, and an enactment of her disciplinary 'hinterlands'), mediated interdisciplinarity by articulating, and thus fostering dialogue around, humanists' disciplinary knowledge practices. In these ways, and in line with Fry and Schroeder's (2010) findings, the present study established

no ‘one-size fits-all’ with regards to how ‘disciplines’ and technologies (and other objects) shape each other, evoking the situated and mediated nature of interdisciplinarity.

Embodied (by technologies-in-development)

The ‘situatedness’ of interdisciplinary socio-material research practices was also suggested through the ‘embodiment’ of interdisciplinarity by (and *within*) technologies-in-development in this study. Technological development is inextricably linked with the research aims across all three cases, and the findings indicate that technologies-in-development in ‘interdisciplinary’ research projects in Higher Education may be constructed as sites of interdisciplinary coordination and negotiations. ‘Embodied’ interdisciplinary knowledges (and methodologies), particular to each research project, are inscribed in, and constructed *through,* technologies-in-development. For example, during the laboratory construction for the Energy project (CS3), technologies-in-development began to ‘interact’ in some of the ways laid out in the grant proposal at problematisation, prompting (interdisciplinary) negotiations between humans and non-humans, most notably the technologies and their respective development teams. The technologies-in-development ‘took the lead’ in the emerging interdisciplinary collaborations, driving interdisciplinary enrolments of a wide variety of (inter/disciplinary) actors. As the modular technologies were drawn together into one central Energynet platform, they simultaneously brought together their (disciplinary) development groups. One instance of this was described when Lilian joined Marco in setting up the fuse in the laboratory, prompting her to make advancements in her work on the project simulator within the Energynet platform.

Additionally, in the Digital Humanities case (CS2), whilst the concept token was not fully inscribed into the Data Biro software, resisting a fully ‘practical’ mobilisation, there was nonetheless the *ambition* towards the technological ‘embodiment’ of inter/disciplinary practices. These findings are supported to a certain extent by the National Academies’ report’s (2005: 35) argument that ‘generative technologies’, defined as ‘those whose

novelty and power not only find applications of great value but also have the capacity to transform existing disciplines and generate new ones', are important within interdisciplinary research. Klein (2015: 28) also found that 'disciplinay traditions… are in active interplay with the technologies even as the technologies are transforming the traditions'. But I argue that it is more complex than these contentions, as 'technical objects… simultaneously embody and measure a set of relations between heterogenous elements' (Akrich, 1992: 205). 'Interrelations between disciplines… are embodied in interdisciplinary assemblages' assert Barry and Born (2013: 6), and the findings similarly suggest that the technologies-in-development across the three cases, as (components of) socio-material interdisciplinary assemblages themselves, embody situated 'interrelations between disciplines'. The Findings chapters illustrate how 'technologies do not simply exist; they *become*' (Sørensen, 2009: 59). Technology is (interdisciplinary) 'know-how embedded in an artefact' (Strathern, 2004: 18), such that the materiality of interdisciplinarity, in part, *is* technology. Technologies-in-development in interdisciplinary research projects *are* situated (interdisciplinary) socio-material (research) practices.

7.2.2 Emergent (inter/disciplinarity)

In a similar vein to the 'situatedness' of interdisciplinarity, the findings of this study suggest that the socio-material practices of interdisciplinarity, in research projects co-developing new technologies, are *emergent*. Interdisciplinarity is not one 'eureka moment of scientific insight' (Jacobs, 2013), and 'interdisciplinary, collaborative work requires continuous negotiation and co-construction of outcomes' (Haythornthwaite et al., 2006: 155). Whether interdisciplinary practices are inscribed, or are transient, interdisciplinarity is emergent; it is, as tentatively suggested during the literature review, 'in-the-making'. For example, emergent interdisciplinarity was constructed and inscribed by and within the CT scan images in the Medical Robotics case (CS1). Just as the 'disciplinary' objects in this case, such as the CT scanner and ultrasound units, represented various, embedded

disciplinary enactments as traditionally 'clinical' objects, so the CT images became *interdisciplinary* inscriptions, 'capturing' the emergent interdisciplinarity of the case.

Furthermore, building upon Chapter 2 (Literature Review), I now argue that *both* disciplinarity and interdisciplinarity are emergent (e.g. Brew, 2007; Barry and Born, 2013). As Mattila (2005: 16) proposes that interdisciplinarity is 'in-the-making', the findings suggest that interdisciplinary and disciplinary practices are in-the-making simultaneously; they are 'part of the same thing'. Socio-material practices of interdisciplinarity emerge as socio-material practices of *disciplinarity* emerge. This is particularly interesting in relation to Mulcahy's (2013: 5) contention, drawing empirically from an interdisciplinary project to investigate collaborative research through ANT, that there is 'no clear divide between the disciplines and interdisciplinarity… [they] are always and already entwined'. Graff (2015) similarly suggests that it makes little sense to define 'interdisciplinarity' in general terms, arguing that both disciplines and inter-disciplines are emergent constructs that continuousy shift the boundaries of knowledge-making. Interdisciplinarity and disciplinarity are sets of related *emergent* practices:

> 'In thinking about the relations between disciplinarity and interdisciplinarity [it is]… a mistake to contrast the homogeneity and closure of disciplines with the heterogeneity and openness of interdisciplinarity… Disciplinary boundaries are neither entirely fixed nor fluid; rather, they are in relation and in formation' (Barry and Born, 2013: 7 – 8)

The difference between the ways in which disciplinarity and interdisciplinarity (as traditionally conceived) were practised across the cases (and more broadly), however, is that disciplines have been constructed, enacted and repeatedly re-enacted to the extent that they have become black-boxed and assimilated in the power structures of the University. Interdisciplinarity has not (to the same extent).[113] 'If things [such as

[113] Concepts of 'disciplinarity' have been brought to the foreground through my findings, building upon the literature review which established that "[r]ecognising ambiguities in the concept of 'discipline' foreshadows the challenge of defining interdisciplinarity" (Aram, 2004: 381).

disciplines] seem solid, prior, independent, definite and single', Law (2004: 56) proposes, 'then perhaps this is because they are being enacted, and re-enacted, and re-enacted, in practices'. Findings from the interviews in particular suggest a pervasive 'dualist' (or, 'quantifiable') 'disciplinary black-boxing' of other actor's (disciplinary) practices. This reinforced a rigidity in understanding disciplines as 'fixed' rather than emergent by many project researchers. Indeed, Busch (1997) argues that University knowledge disciplines and practices can be heavily black-boxed. This took place across the cases, between Medicine and Engineering (CS1), Humanities and Engineering (CS2), and Engineering and other disciplines (including the Social Sciences) (CS3). For example, binaries and 'dichotomies', particularly between the technical and non-technical, were constructed in the Medical Robotics case (CS1), when researchers were described as 'thinking like a doctor' or 'thinking like an engineer'. Additionally, in contrast to the Medical Robotics and Energy cases (CS1, CS3), which were found to be primarily 'engineering-driven', the 'discipline' of engineering was positioned as an 'outsider' in the Digital Humanities case (CS2), on the periphery of the moving boundaries of the network. This illustrates two points: firstly, that there may be a 'space' between how emergent interdisciplinarity is practised, and how most researchers think about it. This is supported by Donaldson, Ward and Bradley's (2010: 1531) findings who explain that '…the researchers on our project could very clearly express in principle what they meant by interdisciplinarity, by using the conventional language of the field. Mapping those clear ideas onto practice is more difficult, because they are ideal types and interdisciplinary practice… is inherently about dealing with mess'. Secondly, building upon this, there is therefore a 'space' between how emergent *disciplinarity* is practised, and how many researchers from 'other' disciplines across the three cases think about it.[114]

[114] Emerging heterogeneity between actors traditionally in 'the same' disciplinary group was also illustrated across all three projects, particularly between Pete and Mina as clinicians within Medical Robotics (CS1).

7.2.3 Irreducible to antecedent 'parts'

As laid out in Chapter 2 (Literature Review), interdisciplinarity is (problematically) typically conceptualised as disciplinary synthesis or integration. The phenomenon is often organised around integrative 'models' in which interdisciplinarity is thought to happen through the integration of two or more 'antecedent disciplines' (Tait and Lyall, 2001; Mansilla and Gardner, 2003; Nowotny, Scott and Gibbons, 2003; Barry and Born, 2013: 10). In the review of literature, I challenged this framing as too 'simplistic', agreeing with Newell (2001) that such complex phenomena cannot be understood adequately by using 'reductionist' disciplinary approaches. Like Donaldson, Ward and Bradley's (2010) study, and akin to Barry and Born's (2013) agonistic-antagonistic mode of interdisciplinarity, my findings now show how the socio-materiality of interdisciplinary practices 'rub up against' these 'conventional' ideas of interdisciplinarity.

However, what I had originally dismissed entirely as truisms can now propel forward discussion of this study's findings regarding the relationships, not only between interdisciplinarity and its 'precursor' disciplines, but moreover between all 'parts' of the disciplinary 'assemblages' which precede the construction of new interdisciplinarities. The findings from the three cases suggest that the socio-material practices of interdisciplinarity in research projects co-developing new technologies are irreducible to their antecedent 'parts'. That is, interdisciplinarity is greater than the sum of its disciplinary parts, and as such an 'integrative' model of interdisciplinarity, identifying a discrete 'formula' for interdisciplinarity, is definitely not suitable. Indeed, Gorman (2004), when outlining what he perceives as the 'conditions necessary to facilitate truly multi-disciplinary collaboration' by borrowing from Galison's (1997) metaphor of trading zones, argues that, 'to create new technologies that extend human capabilities in beneficial ways, we will need to develop new ways of working together… converging technologies require converging aspirations in which individual ambitions for particular disciplines, institutions and careers combine into a whole that is greater than the sum of its parts'

(Gorman, 2004: 36). In this way my findings draw a closely aligned parallel with Barry, Born and Strathern's (2007: 28) who put forward that a 'new interdiscipline [is] irreducible to and incommensurable with its antecedent disciplines'. They add in a later account of the study that '… the relation between interdisciplinarity and the generation of novel objects and practices… are irreducible to their antecedent conditions and disciplinary progenitors' (Barry and Born, 2013: 38 – 39).

This was illustrated particularly well by the Digital Humanities case (CS2). It can be argued that the Digital Humanities are recognised as a nascent interdisciplinary field, or '(inter)discipline', in Higher Education, to a greater extent than Energy or Medical Robotics (Berry, 2019).[115] Not only was this apparent from how the researchers in this case spoke about the field in comparison to the researchers from the other cases about their respective fields, but there is also a vast and growing area of study around the Digital Humanities, alongside the emergence of dedicated centres, institutes, networks, associations, as well as conferences, journals and University courses. 'Perhaps more than any other area of the academy, the digital humanities have succeeded in making linkages across disciplines that are radically disparate in focus and methodology', argue Davidson and Savonick (2017: 161). Indeed, the Digital Humanities, despite internal, definitional disparities, as reinforced through researcher interviews in this case, is commonly understood as 'interdisciplinary',[116] and an interdisciplinarity enacted through the (theoretical) translation in the Digital Humanities case is irreducible to its antecedent

[115] Interest from the STS community towards the Digital Humanities led Bruno Latour to deliver the opening plenary lecture 'Rematerialising Humanities Thanks to Digital Traces' at the 2014 Digital Humanities conference.

[116] Desfriches-Doria et al. (2018: 45) argue that '…interdisciplinarity is embedded within DH's ordinary practices', and Berry and Fagerjord (2017: 20) add that 'the interdisciplinary nature of digital humanities: it is always a marriage of insights and methods from computer science with methods, questions and theories from the humanities'. Klein (2015: 15) explains that the Digital Humanities have "…been variously dubbed a 'discipline,' an 'interdiscipline,' an 'interdisciplinary field,' an 'array of convergent practices,' a set of 'heterogeneous constituencies,' and a 'nexus of fields'". Liu (2009) goes so far to label Digital Humanities as an 'exo-disciplinarity', with Kirschenbaum (2014: 14) adding that the 'digital humanities' is in fact a 'diversified set of practices'. 'As digital humanities form an emergent field of practices, the actors are far from coming up with a unified definition of it… [but] the recently emerging DH field is mostly described as an interdisciplinary one involving a variety of actors…', summarise Desfriches-Doria et al. (2018: 39).

inter/disciplinary actors. This is including, but not limited to, Nicola's agenda driving the importance of external articulation of humanists' research practices; how engineers 'practice' knowledge; conversations on the Slack platform; and Alessandra's diagrams. This is corroborated by Berry (2019) who argues that 'the digital humanities can be understood as a set of interlocking and interdependent parts that, whilst distinct and standing alone to some degree, nonetheless adds up to make the whole greater than the sum of its parts'. Furthermore, much like conceptions of 'interdisciplinarity' as presented in this thesis, Gold and Klein (2016) explain that '…we know DH in large part because it names itself, yet what it names seems increasingly malleable and at times difficult to grasp'. Like the boundaries of disciplines and inter-disciplines, as described in the last section of this chapter, the boundaries of the 'Digital Humanities' field in Case Study 2 are in construction, as the interdisciplinarities of the project emerges. Multiple interdisciplinarities are 'in the mix' of Digital Humanities (Klein, 2015: 15).

7.2.4 (Made of) relational tensions (and multiplicities)

The findings suggest that the socio-material practices of interdisciplinarity (in research projects co-developing new technologies in University X) are enacted through relational tensions. Interdisciplinary knowing is relational, and almost counter-intuitively, interdisciplinary frictions *are* interdisciplinarity. This is supported by the findings of Callard, Fitzgerald and Woods (2015) in their study investigating practices of interdisciplinarity across a large, dispersed team of collaborators in the 'Hubbub' project. They argue that '…tensions are central to, though frequently disavowed within, interdisciplinary (and, no doubt, disciplinary) projects… Such tensions can arise, and have already arisen in Hubbub, over differing epistemologies, ontologies and presumed foci or objects of analytic concern' (Callard, Fitzgerald and Woods, 2015: 4).

Indeed, as explored during the literature review (and re-visited earlier in this chapter), interdisciplinarity is (typically) conceptualised as constructed through disciplinary integration. I, however, disagree with, for example, Haythornthwaite et al. (2006: 147)

who claim that 'interdisciplinary teams are… challenged to integrate not only disciplinary knowledge, but disciplinary practices'. Firstly, as this thesis has laid out, I have argued that (inter)disciplinary knowledges *are* (inter)disciplinary practices. Secondly, the findings across all three cases attribute great importance to the persistence of tensions, alongside some resolutions, through negotiations between (disciplinary) actors. In her similarly theoretically framed study of interdisciplinary research and development practices in a Technology Enhanced Learning (TEL) project, Rimpiläinen (2012: iv) also found that some 'interdisciplinary tensions resolved, while they did not disappear'. As such, Rimpiläinen's (2012: 259) conclusion that 'respective hinterlands [of] the researchers produced divergent realities' backs this study's findings. The researcher's disciplinary 'hinterlands' participated in generating their realities-in-the-making and thus divergent research practices, creating resistances, as well as productive frictions.

The multiplicities of (interconnected) interdisciplinary realities, illuminated through the narratives of the previous three chapters in this study, elucidate enactments of the socio-materiality of interdisciplinarity through relational tensions and frictions. The multiplicities across the cases of this thesis can be divided, for the sake of this narrative, into two broad categories: the multiplicity of (inter/disciplinary) objects, and the multiplicity of interdisciplinarity – with further discussion around the enduring tensions within each of these.

Multiplicity of (inter/disciplinary) objects

As will be further explored in section 7.3, with the deliberate methodological and theoretical choice in this study to 'move' from epistemologies towards ontologies, from perspectives to realities (Mol, 2002), my findings brought (interdisciplinary) objects into the foreground, making 'space' for their multiplicity. 'Sometimes the best way to tackle the mess of an interdisciplinary object is to acknowledge its multiplicity and not try to reduce that through synthesis', explain Donaldson, Ward and Bradley (2010: 1533 – 1534). Indeed, through exploration of the multiplicities of (inter/disciplinary) objects, rather

than 'reducing them through synthesis' as much existing literature on interdisciplinarity has done, the findings have illustrated the relational tensions through which interdisciplinarities are constructed. For example, exploring frictions in the multiplicity of the needle in the Medical Robotics case (CS1) allowed me to become attuned to multiple interdisciplinarities-in-the-making. Across the four moments of translation, the needle acquired new, overlapping roles corresponding to different sets of (inter)disciplinary practices; that is, different 'versions' of the needle, including its participation as a 'theoretical playground' in robotics research, an engineering design task during interessement, and 'something to be tested' by Mina and Jennifer.[117] Interdisciplinary coordination work during this period was mediated by this multiplicity (Akrich, Callon, and Latour, 2002; Mol, 2002).

These findings are strongly supported by Donaldson, Ward and Bradley (2010: 1526) who contend that 'objects are multiple: rather than different perspectives there are various sets of practices which articulate different, though interrelated, objects. If we look at practice rather than opinions, objects appear clearly as fluid and multiple, brought into being in multiple sets of differing practices, yet linked together… The objects around which interdisciplinary research is oriented are constructed and articulated through multiple research practices'. [118] 'Relational' tensions constructed through this multiplicity *are* the 'matter' of interdisciplinarity. Socio-material enactments of interdisciplinarity *are* the frictions which exist among and between (partially connected) (interdisciplinary) objects.[119]

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[117] A particular instance of this was described when, during the in vivo experiments, the difference between the engineer's and the radiologist's conclusions was grounded in the different ways in which they accomplished the needle and its experimentation.
[118] During the Digital Humanities case (CS2), when discussing the emerging multiplicity of the 'concept', I had briefly considered whether a useful term to describe certain 'interdisciplinary' research objects might be Star and Griesemer's (1989: 387) 'boundary object'; that is, an object that is 'adaptable to different viewpoints … and robust enough to maintain an identity across them'. However, my analysis takes note of Donaldson, Ward and Bradley's (2010: 1532) comment that the term 'boundary object' implies an essentially epistemological approach.
[119] Where an 'object' can be knowledge, technology, methodology or the research problem itself, for example.

Multiplicity of interdisciplinarity

Through illuminating the multiplicities of (interdisciplinary) objects, the findings of this study have elucidated the multiplicities of researchers' realities and (inter)disciplinarities-in-the-making, and the resulting and enduring relational tensions. Multiple 'interdisciplinarities' exist, and Huutoniemi et al. (2010: 80) begin to acknowledge this when they claim that 'interdisciplinarity is… best understood not as one thing but as a variety of different ways of… confronting the prevailing disciplinary approaches'. Indeed, the findings of this thesis support Barry and Born's (2013: 5) call to 'understand interdisciplinarity less as a unity and more as a field of differences, a multiplicity', as different project actors performed and mobilised 'interdisciplinarity' differently across the three cases. One 'catch-all' term thus does not provide enough analytical purchase (Barry and Born, 2013). For example, researchers 'understood' and practised interdisciplinarity in multiple ways in the Digital Humanities project (CS2), in large part, according to their disciplinary 'hinterlands', as well as the multiplicity, malleability and fluidity of the concept token. Consistent with Nicola's positioning of 'interdisciplinary self-awareness' at the point of problematisation, project researchers were forthcoming with their thoughts and opinions on the nature of interdisciplinarity within the project. For Ren, interdisciplinarity was 'interest-based', but for David, it was a 'necessary context' within which to foster a new field of humanities data visualisation.

Similarly, within the Energy project (CS3), conceptualisations of interdisciplinarity, its role on the project, and in particular emphases on relationships between the 'different disciplines' within the engineering field, differed broadly between researchers. As stated, rather than differing viewpoints, this suggests emerging, diverse (interdisciplinary) realities: '…the different sides of the controversy are presenting not differing perspectives, but different, partially connected objects' (Donaldson, Ward and Bradley, 2010: 1532). These competing, and overlapping, emerging interdisciplinary realities (including whether or not each project was 'interdisciplinary' for different researchers) are partially

constructed by researcher differences in how they conceptualise a discipline, and a 'spectrum' of interdisciplinarity. In these ways, my findings respond well to Szerszynski and Galarraga (2013: 2817) who propose '…a more reflexive imaginary for interdisciplinarity, one that challenges the idea of integration and subordination, that promotes and benefits from the multiplicity and heterogeneity of ways of seeing that different disciplines offer'. The multiplicity of interdisciplinary knowledge practices, with actors mobilising interdisciplinarity in different ways - grounded in the diverse ways in which they accomplish (inter/disciplinary) objects - generates the relational tensions inherent within socio-material enactments of 'interdisciplinarity' (however it is performed).

Enduring tensions

The findings suggest that the 'matter' of technologically-mediated interdisciplinarity can be performed through relational frictions. Indeed, Lury (2018: 9) acknowledges the 'friction that is often – perhaps always – involved in interdisciplinary research', and Strathern (2005: 130) argues that 'one knows one is in an interdisciplinary context if there is resistance to what one is doing'. It is therefore important to touch upon how these enduring, relational tensions 'played out', or 'coordinated', through the processes of translation across the cases (to be further discussed in section 7.3.2).

Although I have drawn from Mol's (2002) concept of 'ontological politics', as presented in Chapter 2, I now re-visit and question some nuances of her framing of these tensions stemming from multiplicity. Law's (2007) review of her argument communicates well my reservations:

> "Mol [argues] that successful translation generates a single coordinated network and a single coherent reality. [But] any such coherence, if it happens at all, is a momentary achievement… Most of the time and for most purposes practices produce chronic multiplicity. They may dovetail together, but equally they may be held apart, contradict, or include one another in complex ways." (Law, 2007: 152)

Coordination during (interdisciplinary) mobilisation (and indeed, during any other moment of translation) did not necessarily form a 'single coherent reality' since, as it has been shown, relational tensions are crucial enactments of interdisciplinarity.[120] For example, there was no translation presented for the Energy project (CS3), but interdisciplinarities were nevertheless performed. There were also enduring tensions as the project was understood as 'fundamental research', yet also as purely an 'applied project', according to different researchers. Marco's positioning of 'interdisciplinarity as application' during problematisation in this case found some resistance in particular as these interdisciplinary frictions emerged. There were strong parallels between these frictions and the emerging tensions in the Medical Robotics project (CS1), as Mina understood their work as an 'impractical proof of concept', whereas Jennifer wanted to apply the robotic needle platform directly to the market, for use in surgery. This also resembles tensions between Nicola's framing of the Digital Humanities project (CS2) as a 'tiny experiment', in contrast to the engineers' understanding of the project as more 'applied', in working software.

In these ways, my findings and analyses advance a somewhat uncomfortable friction between the idea of 'translating' interests of actors towards one actuality (and the 'traditional' conceptualisations of interdisciplinarity as integration and syntheses), and the enduring tensions of interdisciplinarity. Rather than view this as a methodological 'fault', or an incompatibility between interdisciplinarity and ANT as a 'frame', however, I argue that this is, and that I have 'used' this as, a *generative* tension between the ANT assertion that networks inevitably suppress 'other' voices (in order for a translation to occur), and (traditional) interdisciplinary attempts to explicitly include and negotiate conflicts between diverse disciplinary 'inputs'.[121] 'Interdisciplinarity is as much marked by agonism and antagonism as by cooperation and collaboration', states Michael (2017: 123),

[120] Law (2002) refers to coordination as the ways in which multiplicities can relate to one another. 'Multiplicity and coordination go together', reinforces Sørensen (2009: 82).
[121] As stated, this will be further discussed in section 7.3.2.

continuing that interdisciplinary 'reality is enacted through practices [as] these different realities butt up against each other [as] other practices manage this diversity and disparity' (Michael, 2017: 125). The methodolodogical and theoretical framings of this thesis have 'opened up' the enduring tensions – as well as the more 'traditional' integrations – of interdisciplinarity.[122]

7.2.5 Distributed

The findings suggest that socio-material practices of interdisciplinarity in research projects co-developing new technologies are distributed, not only across actors and spaces within University X, but also *outside* of the University. In this way, whether performed inside or outside the traditional bounds of the academy, the findings indicate that interdisciplinarity can be conceptualised as a way of bringing 'new socio-materiality' into being, that's not constructed *comfortably* in the prevailing 'power structures' (Graff, 2015) – disciplinary departments – of the US University.

Interdisciplinary spaces in the University

(Physically-bounded) spaces within University X across the three cases were, like the technologies-in-development, found to be constructed as sites of situated interdisciplinary coordination, negotiation and trials of strength. For example, the Zeevo lab (CS1), although located in a traditionally medical space in the basement of the University X hospital, drew together 'engineering objects' and other actors from the Robotics lab (as well as actors from inside and outside of both labs) during the experiments, constructing interdisciplinarities. This 'space of inquiry' was 'reworked to accommodate interdisciplinary research objects' (Tily, 2016: 32). The Zeevo lab participated as a site of interdisciplinary negotiation, where multiple ontologies entangled, dis-entangled and coordinated in different ways. The Energynet lab space (CS3) also mediated

[122] I like the 'theory' by Donaldson, Ward and Bradley (2010: 1526) that 'as all attempts to order involve exclusions and losses (Law, 2004), interdisciplinary approaches could be seen as a way to minimise these'.

interdisciplinary practices. In particular, through Marco's enrolment of the lab, and the lab's enrolment of other actors, interdisciplinarities were performed, and differences (and realities) were (un)settled and (re)configured. It is in part through the enrolment of both these laboratories that heterogeneous actors and assemblages were drawn together and enrolled in the project networks in interdisciplinary ways.

In these ways, and as might have been expected, the findings show how 'the historical and institutional conditions within which interdisciplinary initiatives are implanted make a difference' (Barry and Born, 2013: 39). It is therefore important to note the increasing number of 'institutionalised' spaces specifically for and of interdisciplinarity within University X (and other institutions), including the interdisciplinary 'Hub' within which I was located during my fieldwork, and the Centre for Digital Humanities, within which Case Study 2 was based. The Hub in particular had implications for interdisciplinary knowledge practices both inside, and external to, the University, and these will be dealt with in Chapter 8.

Interdisciplinary spaces among the University and 'external' actors

This particularly concerns the interdisciplinarities of Energy case study (CS3), which were found to have implications for the movement of technologies developed in an academic locale across (disciplinary) boundaries into a commercial setting. The framing of the Energy project at problematisation proposed that, not only different disciplinary areas should 'come together' within academia, but also that academic, industry and government stakeholders would work together in 'interdisciplinary' ways, in order to tackle the Energy challenges around which the grant proposal was based. External stakeholders were involved from the point of problematisation, such as the National Lab and a high-profile technology company, and interestingly many researchers conceptualised the business participations as 'inter/disciplinary inputs'. However, Marco's status as a graduate student researcher, and the project's situation within a university environment, undermined the mobilisation of the technologies developed by the Energy project into

industry (and thus the wider Energy 'ecosystem'). There were also tensions between the project goals of 'real-world' application and the academic environment of University X, particularly visible towards the later stages of translation, and these will be further explored in the following section.

Having explored and discussed the situated, emergent, irreducible, multiplicitous, and distributed nature of the socio-material practices of technologically-mediated interdisciplinarity as enacted through the cases, attention must now be turned towards how ANT has assisted *and* resisted my efforts to explore interdisciplinarity. How has this thesis 'got to know' these 'matters' of interdisciplinarity?

7.3 How can we 'get to know' the 'matter' of technologically-mediated interdisciplinarity?

As stated in the introduction to this chapter, there have been tensions running through the findings of this thesis, most notably: how can we accommodate the sprawling complexities of technologically-mediated interdisciplinarity when studying it and writing about it, without totally domesticating it? Although I did not initially foresee such a friction before beginning the study, this has become an interesting finding in and of itself. As such, this thesis has illuminated the socio-material practices of interdisciplinarity (within a research project developing new technologies, in a US University), by drawing from Actor-Network Theory (ANT), in the following ways:

I. By moving away from (inter)disciplinary perspectives, towards (inter)disciplinary realities
II. By following processes of translation as technologies are developed (in interdisciplinary ways) - and embracing the resulting generative tensions

7.3.1 (I) By moving away from (inter)disciplinary perspectives, towards (inter)disciplinary realities

Non-humans are shown to participate in interdisciplinarity

As is clear from this chapter, and as was established earlier in the thesis, this study has deliberately moved away from (inter)disciplinary perspectives towards (inter)disciplinary realities through its theoretical and methodological framing. 'It is no longer a matter of different perspectives on a single object but the enactment of different objects in the different sets of relations and contexts of practice', explain Law and Singleton (2005: 342). In order to move away from purely epistemological 'concerns' of interdisciplinarity, towards ontological - that is, towards (interdisciplinary) objects of research, rather than solely human researchers' experiences of interdisciplinarity - the case narratives attuned to non-human as well as human actors' participations in emerging interdisciplinarities. For example, the choice to 'follow' two non-human tokens through the moments of translation, the needle (CS1) and the concept (Cs2), was deliberate. As such, through the theoretical foundations of this study, non-humans have been shown to participate in interdisciplinary practices. The findings are corroborated by Nimmo's (2016) assertions that:

> "[The] production of [interdisciplinary] knowledge did not just involve human beings and their social actions, but was dependent on a whole array of nonhumans: material things, including laboratory equipment…; apparatus for measuring;…published and unpublished documents of all kinds… The process of knowledge production was not just 'social', in the narrow sense of being a product of human activities, but was a construction accomplished within heterogeneuous socio-material practices in which multiple human and nonhuman[s] were woven together" (Nimmo, 2016: xxxi)

The findings suggest that non-humans, particularly technologies-in-development, participate to a great extent in co-producing interdisciplinary knowledge in research

practice within Higher Education. 'The practice of interdisciplinarity is variously social, material and textual' (Mulcahy, 2013: 6), and I agree that 'by considering the ontological dimensions of mess the whole range of objects that are involved in interdisciplinary research is brought into focus' (Donaldson, Ward and Bradley, 2010: 1521). For example, the narrative during the Medical Robotics case (CS1) described how the needle-engineer-robot-software hybrid was drawn towards the radiologist-ultrasound-computer-pig-CT hybrid in an interdisciplinary alliance during the Zeevo experiments. In this way my findings are strongly supported by Barry and Born's (2013) conclusions that:

> 'Interdisciplinarity should not be thought of as a historical given, but as mobilising in any instance an array of… institutional forms, theoretical statements, instruments, materials and research practices – interdisciplinary assemblages… Such assemblages enact a variety of interrelations between disciplines." (Barry and Born, 2013: 10).

Each research problem becomes multiple

Through the move away from (inter)disciplinary perspectives towards (inter)disciplinary realities, the findings suggest that perceived 'problems' in interdisciplinary practice may be attributed to what was termed 'plurality underlying assumed singularity' by Rimpiläinen (2012: 193). That is, interdisciplinary researchers do not often acknowledge the multiplicity of the 'singular' problem which they are tackling. Michael (2017: 125) describes this as 'a particular unquestioned common reality [that] is tacitly assumed'. This is interesting with regards to Fenwick and Edwards' (2010: 158) suggestion that this can often be due to 'pressures' for researchers within a project to produce one singular 'account' (rather than represent the multiplicities). Indeed, this is reminiscent of Rimpiläinen's (2015: 148) musing on her own study of interdisciplinarity that:

> 'Which reality-in-the-making is allowed to continue to exist becomes a political question. For a short while… realities- in-the-making were allowed to co-exist, but

> [there are] pressures by the collaborative project with a shared purpose [to start] translating the findings' (Rimpiläinen, 2015: 148)

In the Medical Robotics (CS1) case, Pete's 'take' on ablation – that there are more advanced ways to perform the procedure on a patient in practice - was displaced when he finally agrees that the needle's purpose in the project is not to ablate, but rather to establish the 'best' path through the liver tissue. Jennifer's enactment of the needle, its 'reality-in-the-making' as 'something to be tested' in an engineering design task, was privileged through this interdisciplinary coordination work within the actor-network – and it is something to which Pete comes to subscribe.

Researchers across the interdisciplinary project cases within this thesis might at first have *appeared* to be engaged in a common, single problem (within each case, respectively), but they enacted this in different ways, in particular according to their disciplinary and interdisciplinary 'hinterlands' (Law, 2004). For example, the episode of disagreement above between Pete and Jennifer (CS1), particularly when publishing an article (itself an interdisciplinary inscription as a result of a translation), strongly suggests a lack of explicit 'acknowledgement' around the multiplicity of a supposedly 'singular' interdisciplinary problem.[123]

7.3.2 (II) By following processes of translation as technologies are developed (in interdisciplinary ways) - and embracing the resulting generative tensions

As noted earlier in this chapter, there is a tension between an ANT assertion that networks inevitably suppress 'other' voices (in order for a translation to occur), and (traditional) interdisciplinary attempts to explicitly include and negotiate conflicts between diverse disciplinarities. I have used this in a generative way, particularly by exploring the relational tensions which construct interdisciplinarities in research in Higher Education, and as such this deserves some further discussion. These productive frictions between the

[123] This is closely linked to the multiplicity of the needle, as presented above. 'Politics of purpose' are in construction with the multiple 'realities-in-the-making' and multiple needles.

theoretical underpinnings of this study, and the objects of study as 'traditionally' understood, 'open up' further discussions of the phenomena.

Inter/disciplinary tokens illuminate practices through translations

The three (inter/disciplinary) tokens followed through the cases brought practices and co-productions of technologically-mediated interdisciplinarity into the foreground in various and nuanced ways. Tokens in particular brought into focus certain processes of translation, which in turn productively brought interdisciplinarity into view.[124] All three tokens (all devices of interessement) shaped, and were shaped by, other actors to enact interdisciplinarity across the cases. They differently participated in interdisciplinary practices, contributing to the consolidation of (interdisciplinary) alliances in different ways. For example, the Medical Robotics (CS1) research proposal brought together the needle and accompanying robotic technology with a clinical application, and in turn the needle began to draw together the 'inter/disciplinary' fields of robotics and medicine, and their human 'spokespersons'.[125] The needle was both an object *of* and *for* interdisciplinary coordination, pulling other actors and their interests closer to the (interdisciplinary) project plan. Somewhat counter-intuitively, through the resistance of the needle's path, as well its resistance to being visualised via ultrasound, the needle enrolled allies during these experiments. The second case token, the concept of 'encoding a humanities epistemology into a technology' in the Digital Humanities project (CS2), had a close relationship with the (interdisciplinary) project aims, as well as the 'interdisciplinary lab' within which the project was housed. The human token in the Energy project (CS3), Marco (a graduate student and project manager), 'sat' embedded within, shaping and shaped by, the project's complex network of relations, through which he - and other actors - constructed his distributed, relational and interdisciplinary identity. Marco's agency, his

[124] It is important to note that all three cases have similar points of problematisation due to their shared 'status' as research projects.
[125] As stated, this dichotomy was constructed by the human researchers during the project; broadly, a 'dualism' between mechanical/technical/engineering and clinical/medical fields.

role as an interdisciplinary 'knowing location', was in-part constructed by his 'situatedness' at interdisciplinary boundaries, not only between academic disciplines (as delineated by University X), but also between academia and industry.[126] These tokens, followed through processes of translation across the cases, helped to illuminate socio-material practices of interdisciplinarity by, almost paradoxically, bringing forward tensions between how these networks suppressed certain voices, at the same time as explicitly including others.

The nature of mobilisation in 'interdisciplinary' projects: 'success' for whom?

Technologically-mediated interdisciplinarity has been elucidated across the three cases, as the narratives followed each token towards translation. Through this methodological approach, there has been an interesting, multilateral interplay between different ideas of 'success' (interdisciplinary or otherwise), particularly for the researchers, as well as for the nature of the projects' (interdisciplinarity) translations. Therefore, some critical reflection on the nature of mobilisation and the complexities around project 'success', and its relationship with interdisciplinarity, is necessary. What is interdisciplinary mobilisation, and what might it mean for interdisciplinary projects to be 'successful' during enrolment and mobilisation? How are 'success' in mobilisation, and 'success' in interdisciplinarity related? For all three cases, 'interdisciplinary success' was broadly defined by the project researchers as 'fulfilling' their planned project vision; in other words, performing the 'imagined futures' of the 'heterogeneous engineers' through (interdisciplinary) translations (Jasanoff and Kim, 2015). For example, for Mina and Andrea (CS1), two technological aims were laid out in the interdisciplinary research proposal: alongside

[126] More broadly, it could be interesting to consider whether such a 'champion' is needed for interdisciplinary projects (particularly during problematisation), and if so, what does this say about interdisciplinarity? This is view held by the 'Hub', acting as a 'catalyst' for interdisciplinarity. Researchers across the cases also agreed, including Nicola (CS2) who (referring to herself) thinks that 'what makes interdisciplinarity successful is in part someone to help orchestrate that', and Raj (CS3) explaining that 'what I notice is that most interdisciplinary projects fail because they have people from different disciplines, but they don't have anybody who connects them' (e.g. Gorman, Groves and Shrager, 2004).

goals to improve needle precision during liver RFA procedures, and to validate its potential for clinical adoption, the proposal set out to develop the use of ultrasound for needle location. As the findings show, however, only one (CT imaging) was mobilised to some extent; the ultrasound imaging resisted. This suggests a 'privileging' of the engineers' 'failure' reality, deeming the experiments to fail, versus the surgeons who saw it as a 'success'. Enactments of (interdisciplinary) success and failure during mobilisation, particularly in relation to the needle, were different for the clinicians and the engineers.

Additionally, 'dual aims' were laid out at problematisation in the Digital Humanities project (CS2): 'technological' – developing the Data Biro software – and 'theoretical' - development of methodological knowledge around 'digital humanities' practices. A 'theoretical' translation of the token happened, up to a point, but there was not an 'equivalent' enactment of the concept 'technologically'; the *idea* of the interdisciplinary concept (of 'encoding an epistemology') was mobilised, while the technological integration resisted. This represented a 'success' for Nicola – a privileging of her ontology - as her ideas were mobilised in others' dialogue, but a failure for the engineers (positioned on the peripheries of the moving boundaries of the project), whose (interdisciplinary) 'success' was dependent on the production of a finished prototype technology. Ultimately, a 'version' of (Nicola's) interdisciplinarity was actively engaged, as was exemplified during the final workshop when the technical researchers 'bought into' Nicola's concept through the 'basil+Germany' example. This coalescing around Nicola's theoretical vision displaced other ontologies and their 'versions' of 'success' for the project. In this respect, this was *Nicola's* mobilisation (of her 'thought experiment'); a 'successful' realisation of her ontology. 'Conflicting ontological politics have unfolded' (Mol, 1999: 79).

Interdisciplinarity was not practiced to the same extent during mobilisation for the Energy project (CS3). According to the Energynet pamphlet, which equated 'success' for the project with its facilitation of the idealised 'energy future', alongside Marco's framing of interdisciplinarity as 'application', there were 'breakdowns' in interdisciplinary

mobilisation. Although shared visions of an 'ideal' Energy future, potentially achieved through real-world applications of the technologies-in-development, interessed actors, technologies developed through the Energy project 'struggled' to leave the University environment for representation in industry - and thus were not mobilised through 'tech-to-market' commercialisation. The network struggled to mobilise according to Marco's motivations and framings of interdisciplinary 'success'. Yet whilst the network was not durable enough for representation in industry, 'failing' to enact part of the project 'vision', as it had been defined at problematisation, some situated interdisciplinarities were nevertheless performed. Interdisciplinarity is not *only* 'brought about' by a translation, and different interdisciplinarities were mobilised at different times across the narratives.

Interdisciplinary coordination

The Findings chapters evoked the socio-materiality of technologically-mediated interdisciplinarity in ways akin to Barry, Born and Weszkalnys' (2008) assertion that interdisciplinarity can be conceptualised in terms that capture 'coordinations' across disciplinary and interdisciplinary practices. Likewise, my findings are supported by Lury et al.'s (2018: 281) assertion that, 'with each new interdisciplinary venture new forms of coordination need to arise'. Coordination work took place between competing realities-in-the-making, and these ontological politics were brought about and mediated by the multiplicity of objects. As previously established, interdisciplinary coordination during the moments of translation do not necessarily form a 'single coherent reality', but also consist of relational tensions:

> "Th[e] work of coordinating differently enacted [interdisciplinary] realities… raises a cluster of questions: about who can produce accounts, where, and with what; about which are privileged when there are inconsistencies; about which can be translated, which interfere and which are simply incompatible. It raises political questions about who should be expected to make decisions, but also, about what is worth

> doing and why, and how we should think about the differences, tensions and conflicts that will inevitably arise' (Oliver, 2012: 443)

In these ways, interdisciplinary 'success' was found to be related to interdisciplinary coordination and ontological politics. For example, both Nicola (CS2) and Marco (CS3) framed interdisciplinary 'success' in certain ways according to their own ontologies, and these displaced, or *were* displaced, respectively. In the Medical Robotics case (CS1), interdisciplinary coordinations happened as trials of strength between the pig's anatomy, the ultrasound and the needle negotiated Angelo's and Pete's ontologies. Radiologist Pete's and engineer Angelo's different and competing realities-in-the-making were contested and enacted through the experiment, through the consecutive realisation, and displacement, of both their suggestions at different times. Across the cases, coordination is the materiality of interdisciplinarity. Complex relationships mark the multiple and overlapping, and at times competing, realities for actors across the cases, and these can be understood as disciplinarities and interdisciplinarities in construction and in practice. Frictions between the theoretical underpinnings of this study, and the objects of study as 'traditionally' understood, have thus been harnessed generatively in this study in order to further explore enactments of the socio-material practices of technologically-mediated interdisciplinarity.

7.4 Summary

This chapter has discussed how the thesis has explored the socio-material practices of interdisciplinarity in research projects co-developing new technologies in a US University. Moving away from 'traditional' framings of interdisciplinarity as presented in the literature review, through the theoretical and methodological underpinnings of this study, the findings have shown how interdisciplinarity is situated, mediated and embodied (by technologies-in-development), and does not exist outside its own enactments. Interdisciplinarity *and* disciplinarity (as conventionally conceived) have been shown to be emergent and part of the 'same thing'. It was also found that the phenomenon is

irreducible to antecedent 'parts', made of relational tensions (in part due to the multiplicities of research practice), and distributed across different spaces both inside and outside the University. This chapter also explored *how* such a complex and 'slippery' phenomenon was handled in practice, and how this further productively 'opened up' the investigation of interdisciplinarity, allowing contributions to the existing body of knowledge around technologically-mediated interdisciplinarity, and the broader field of Education.

CHAPTER 8: CONCLUSIONS

This thesis has examined how interdisciplinary research practices are enacted in technology projects in Higher Education. 'Opening up' the unfolding practices of technologically-mediated interdisciplinary research through an enhanced conceptual framing, in order to examine in-depth the nuances of interdisciplinarity as it is assembled, this study has answered the central research question:

> *How are the socio-material practices of interdisciplinarity in research projects co-developing new technologies, in a US University, enacted?*

The study followed three interdisciplinary project teams as they moved from research questions (upon which different disciplinary approaches were brought to bear) to emerging technological outcomes in order to investigate their interdisciplinarities 'in-the-making'. In this way the research reframed the 'traditional' discourse on technologically-mediated interdisciplinarity, largely permeated by technologically deterministic studies, as well as social explanations and tropes, to examine the emergence of socio-material practices of interdisciplinarity. ANT was established as a valuable framing for attuning to and interrogating the complexities of interdisciplinarity as the object of study. ANT privileged neither the human nor the technology in order to generate more critical conceptual understandings of interdisciplinary research in technology projects, particularly within US Higher Education, taking into account its heterogeneities and material participations. This work built upon, and contributes to, the existing body of knowledge around interdisciplinarity, and to the application of ANT in Education, with broad implications for the substantive promotion of a more nuanced view of technologically-mediated interdisciplinary practices.

This research has generated new insights and advanced understandings into how interdisciplinary research happens 'in practice' in projects developing new technologies in Higher Education. In this concluding chapter, I emphasise what has emerged from this praxiographic study, and the contributions the findings have made, particularly to

understandings of interdisciplinarity and the development of new technologies. I will also acknowledge some limitations of the study, re-visit my own researcher positionality, reflect on my findings with regards to implications for future practice, and finally suggest some potentially interesting avenues for further research which could build upon this work.

8.1 Study contributions

Considering the 'laboratory life' of three technologically-mediated interdisciplinary research projects, based at University X (Latour and Woolgar, 1986), this thesis has explored how, moment-to-moment, heterogeneous research teams enact interdisciplinarity 'in-the-making' (Mattila, 2005: 16). Following three different analytical tokens through the moments of translation, unpacking the entwined practices around the 'co-production' of technologies in interdisciplinary research projects in various ways, across a range of disciplines - a Medical Robotics project (CS1), a Digital Humanities project (CS2), and an Energy project (CS3) - this study found that situated, distributed interdisciplinarities are mediated and embodied by technologies-in-development (among other objects), as 'know-how embedded in… [technological] artefact[s]' (Strathern, 2004: 18).[127] The findings also suggested that technologically-mediated interdisciplinarity is irreducible to its antecedent parts, and is 'made of' relational tensions and frictions. 'Interdisciplinarity is as much marked by agonism and antagonism as by cooperation and collaboration', states Michael (2017: 123), and the methodological and theoretical framings of this thesis have 'opened up' the enduring tensions – as well as the more 'traditional' integrations – of interdisciplinarity. These findings brought forward the multiplicities of interdisciplinarity in practice,[128] moving away from conventional framings reducing interdisciplinarity to disciplinary integration, synthesis or boundary-crossing.

[127] Interdisciplinary knowledge practices are local and sometimes inscribed (in interdisciplinary objects), for instance, in the CT scan images (CS1).
[128] 'Being interdisciplinary' is situated and is a different 'thing' each time it is (re)constructed.

Attending to the 'plasma' of interdisciplinarity (Latour, 2012: 93; Callard and Fitzgerald, 2015), this thesis has made visible technologically-mediated interdisciplinarity in practice, drawing to the foreground the multiplicities of interdisciplinarity, that is, multiple interdisciplinarities-in-the-making. Indeed, the findings of this thesis are supported by Barry and Born's (2013: 5) call to 'understand interdisciplinarity less as a unity and more as a field of differences, a multiplicity', as project actors understood, performed and mobilised 'interdisciplinarity' differently within and across the three cases in the collective case study. This multiplicity of interdisciplinary knowledge practices was grounded in the diverse ways in which actors accomplished (inter/disciplinary) objects - in large part, according to their disciplinary 'hinterlands', as well as the multiplicity, malleability and fluidity of objects – which in turn generated relational tensions in the socio-material enactments of interdisciplinarity (however it was performed). In this way one 'catch-all' term does not provide enough analytical purchase considering the multiplicity and transience of interdisciplinary knowledge practices that has been found,[129] and Graff (2015) similarly suggests that it makes little sense to define 'interdisciplinarity' in general terms. My findings thus support Szerszynski and Galarraga (2013: 2817) who propose '…a more reflexive imaginary for interdisciplinarity, one that challenges the idea of integration and subordination, that promotes and benefits from the multiplicity and heterogeneity of ways of seeing that different disciplines offer'.

These findings underpin the three central contributions of this thesis. First, this study has contributed to richer socio-material understandings of (technologically-mediated) interdisciplinarity. This productively responds to the appeal by Born and Weszkalnys (2008: 42) to 'raise the prospect of a re-evaluation of interdisciplinarity', which can 'move discussion of interdisciplinarity beyond the well-worn ruts it has created in recent years' (Donaldson, Ward and Bradley, 2010: 1521). The thesis contributes to the existing body of

[129] As Donaldson, Ward and Bradley (2010: 1535) suggested, this study has successfully moved 'away from the various justifications and conventions that seek to pin down [one]…reality of interdisciplinarity and towards a position in which there is no reality to interdisciplinary research other than that which is made in practice'.

knowledge around interdisciplinarity, in particular around research practices in technology projects. As such, this study adds to emerging research which frames interdisciplinarity through a socio-material lens. For example, in line with Szerszynski and Galarraga's (2013: 2822) findings, as introduced above, 'what we can see emerging here is a model of interdisciplinarity that involves heterogeneous methods and asymmetric contributions, underpinned by… ontological multiplicity' (rather than, for example, an 'integrative' model identifying a discrete 'formula' for interdisciplinarity). By evoking the socio-materiality of interdisciplinarity according to the study's research question, the findings hold broad implications for promotion of a more nuanced understanding of technologically-mediated, socio-material interdisciplinary practices. Akin to Barry and Born's (2013: 41) aims, this study has brought to the fore the 'complex nexus of circumstances bearing on the growth and demise of heterogeneous interdisciplinary assemblages', and like Donaldson, Ward and Bradley's (2010) study, my findings show how the socio-materiality of interdisciplinary practices 'rub up against' many 'conventional' ideas of interdisciplinarity. The findings therefore are also reinforced to a certain extent by the appeal from Albert et al. (2019: 1) to 'critically examine the ubiquitous discourse promoting interdisciplinarity'.

In the same vein, it has been suggested that interdisciplinary and disciplinary practices are in-the-making simultaneously. As put forward by Barry and Born (2013: 8), 'disciplinary boundaries', and as I have found, interdisciplinary boundaries, are relationally defined and 'in formation'. Despite, and rather, in parallel with, 'negotiating… a politics of disciplinary knowledge' during interdisciplinary work (Monteiro, 2018: 156), rather than viewing interdisciplinarity as a 'response' to disciplinarity, the socio-materiality of disciplinarity and interdisciplinarity are 'part of the same thing'. They are both forms of knowledge production; disciplines co-ordinate the practice of research, as does interdisciplinary work. Furthermore, building upon this, Trowler (2014: 23), when reflecting upon practice-focussed ethnographies, or praxiographies, in Higher Education, points out that "academic disciplines are… enacted differently in different contexts yet still

recognisable to the observer as somehow 'the same' even across multiple manifestations". Particularly significant for my findings, I suggest that his reflections on '…the implications for praxiography of taking a view of individual disciplines, like other objects, as multiple… [that] research can pick out the factors at play in conditioning the enactment of discipline in one site', work equally well substituting 'discipline' for 'inter-discipline'.

Second, alongside enhanced conceptual understandings, this study has provided rich empirical accounts and descriptions of interdisciplinarity and technological development 'in practice'. This is a substantial response to Barry and Born's (2013: 2) concern regarding the 'paucity of empirical studies of how interdisciplinarity unfolds in practice'. In chapters 4, 5 and 6, the narrative explored in detail how technologies were developed by interdisciplinary teams.[130] In particular, the richness and depth of each case narrative brought forward (the nuanced complexities of) the roles which technologies-in-development (often as socio-material interdisciplinary assemblages themselves) have in creating new 'inter/disciplines'. It was suggested that technologies-in-development are sites of interdisciplinary negotiation, entanglement and coordination. 'Embodied' interdisciplinary knowledges (and methodologies), particular to each research project, can be inscribed in, and constructed through, technologies-in-development. Indeed, this is supported by Akrich (1992: 205) who comments that 'technical objects… simultaneously embody and measure a set of [interdisciplinary] relations between heterogenous elements', continuing that 'technical objects participate in building heterogeneous networks that bring together… human[s] [and] nonhumans[s]' (Akrich, 1992: 206). Technologies-in-development in interdisciplinary research projects *are* situated (interdisciplinary) socio-material practices, and this has been shown empirically in great detail.

[130] This study has also offered a means to begin to 'capture' technologically-mediated interdisciplinary practices, by using a combination of interviews, observations and other analytical tools, and such an approach serves to add to the growing body of ethnographically-informed research into technical practices in Education.

Third, this study has demonstrated, and reflected upon, the value of Actor-Network Theory (ANT) (and in particular, the four moments of translation: problematisation, interessement, enrolment and mobilisation) for framing, illuminating and advancing understandings of socio-material practices in technological development by interdisciplinary research teams in Higher Education. The principle of translation has productively brought situated and multiple interdisciplinarity to the foreground. This contributes to the application of ANT in the broader field of Education, as well as to the wider 'building site' of ANT in general (Law and Hassard, 1999), where 'ANT theory is created, recreated, explored and tinkered with in particular research practices' (Law and Singleton, 2013: 485).

Such novel theoretical and methodological development, framing a move away from 'conventional' (inter)disciplinary perspectives towards (inter)disciplinary realities, or ontologies, allowed me to de-centre the human and thus move 'beyond a narrowly focused interactionist perspective' to understand interdisciplinary collaboration (Frickel, Albert and Prainsack, 2017: 6), by attending to the (agentic) roles which non-humans play in interdisciplinary practices. In this way the findings brought (interdisciplinary) objects and technologies into the foreground, making 'space' for their multiplicity. For instance, the multiplicity of the needle (CS1), that is, the different ways in which it was accomplished, was found to mediate interdisciplinary coordination work and generate negotiations and resistances, particularly as it moved between traditionally 'engineering' and 'medical' spaces within University X, entangling the (inter)disciplines of robotics and medicine. The moving materiality of interdisciplinarity through the concept and the diagrams (as well as Nicola) in the Digital Humanities case (CS2) also fostered such practices.[131] During the Energynet laboratory construction (CS3), technologies-in-development came together in some of the ways laid out in the grant proposal at problematisation, prompting

[131] Moving the diagrams (during the workshops), to 'encode their epistemology', into the Data Biro software - from a (material) domain more typically associated with the Humanities (analogue/pen and paper), to one more typically associated with Engineering (software/digital), mediated the project's interdisciplinarity.

(interdisciplinary) negotiations between the humans and non-human actors entangled with them, most notably the technologies and their respective development teams. By illuminating how non-humans also participated in research practices in Higher Education, an array of humans *and* non-humans were found to participate in research and technological development across the three interdisciplinary projects at University X. Like Mulcahy (2013: 7), I found that that interdisciplinarity is '…performed through material objects (e.g. texts, technologies, artifacts, architectures, bodies) and materialising processes… Knowledge does not reside in individuals; it circulates in relationships, which in turn can coalesce – form seemingly fixed points and foundations (e.g. bodies of interdisciplinary knowledge)'. Human *and* non-humans participate in and enact interdisciplinarity in Higher Education. 'The production of [interdisciplinary] knowledge did not just involve human beings and their social actions, but was dependent on a whole array of nonhumans… a construction accomplished within heterogeneuous socio-material practices in which multiple human and nonhuman[s] were woven together" (Nimmo, 2016: xxxi). As Shapin and Schaffer (1985) proposed that materialities are the means of scientific knowledge-making, I have found that they are the practices of interdisciplinarity, that is, *interdisciplinary* knowledge-making. Acknowledging the depth and complexities of the phenomena, attending to the materiality of non-humans, ANT has thus productively 'opened up' emergent interdisciplinarity in such a way that future studies might build upon this 'use' of the approach.

As discussed in the Chapter 7, there was a generative tension between the ANT assertion that networks inevitably suppress 'other' voices (in order for a translation to occur), and (traditional) interdisciplinary attempts to explicitly include and negotiate conflicts between diverse disciplinarities. However, it was shown, particularly through Case Study 3, that translation does not necessarily need to happen for interdisciplinarity to be enacted. This project network did not 'reach' the fourth and final moment of translation, mobilisation, as technologies developed through the Energy project 'struggled' to leave the university environment, 'failing' to enact part of the project 'vision' – but even so, some

interdisciplinarities prevailed. As such, (total) alignment of the actor-network is not necessary for interdisciplinarity - but, comparing the three cases, translation (and thus alignment of interests, to some extent) is nonetheless a significant factor in fostering interdisciplinarity, however it is performed. Indeed, Singleton and Michael (1993) argue that the stability of networks depends not on their coherence but on their incoherence, and this, though initially counter-intuitive, in turn supports this study's findings around interdisciplinarity as made of relational tensions and frictions.

Drawing on the ANT framing as a conceptual, theoretical *and* methodological practice, ANT sensibilities helped me attend to, and interrogate, processes of (un)settling differently enacted realities across the interdisciplinary project case studies, moment-by-moment, as things (including disciplines) came together, held together, or broke apart. 'Different disciplines' divergent practices… yield divergent ontologies', explained Michael (2017: 125), as Rimpiläinen (2012: 259) concluded that 'respective hinterlands [of] the researchers produced divergent realities'. Indeed, the ontological politics across the cases, as termed by Mol (1999), showed how ontologies entangled and dis-entangled as interdisciplinarities were enacted at different times. Interdisciplinary 'research [was] shown to be, like other areas, a realm of socio-material practice – contingent, emergent and messy' (Fenwick and Edwards, 2018: 10). Differences were (re)configured, and realities and interdisciplinarities-in-the-making co-existed, interfered with each other, or were 'realised', displaced or marginalised. For example, Nicola's reality-in-the-making (her 'vision' of interdisciplinarity, as framed by a 'theoretical' concept) jostled to become realised in enactments of interdisciplinarity, displacing others in the process (CS2). Ontologies do not exist in isolation; 'as Donna Haraway would say, they interfere with one another and reveal what Marilyn Strathern would call partial connections' (Law and Mol, 2002: 10). In this way, among the others presented throughout this thesis, 'sociomaterial researchers in education are gradually creating an in-between place of sociomaterial/STS studies and education, and showing this to be an important area of inquiry' (Fenwick and Landri, 2014: 3).

8.2 Limitations

First, it is important to highlight a potential limitation regarding the practical 'utility' of this study. Oliver (2016: 51) points out that "…sociomaterial analyses of technology cannot draw simple, general conclusions about devices, nor about their social 'impact' or ability to 'enhance', in the way that educational policy desires (Enriquez, 2009)". As such, the 'impact' of this work, in the sense of how it can be applied in the 'real-world', might be questioned by certain groups in the Education field. Indeed, the study has deliberately privileged *practices* of technologically-mediated interdisciplinarity, over more tangible 'barriers to' or 'ways to facilitate' interdisciplinarity, for example. The reasons for this have been articulated clearly in this thesis, but such an approach may nevertheless render the findings less 'useful' in the eyes of some policy-makers or practitioners who remain concerned with issues of 'impact' and 'effectiveness'. I reflect on some potential implications for future practice below, but any further than this would be to over-claim.

Secondly, in Chapter 3 (Methodology), I described the considerations that went into 'cutting' the case networks during fieldwork (Strathern, 1996). Taking an ANT approach, 'following the actors', in particular the tokens – the steerable needle (CS1), the concept of 'encoding a humanities epistemology into a technology' (CS2) and Marco, a PhD researcher (CS3) - through moments of translation across each of the three cases was a way to 'carve out' the emergent network of actors, and to define a scope of exploration that could accommodate the heterogeneity of technologically-mediated interdisciplinarity. However, there was an extensive and complex web of socio-material relations across all three cases presenting numerous possibilities for 'following the actors' at the outset of the fieldwork. As such, and as pointed out by vu Henry (2018), any 'cutting' of the network inevitably curtailed, to a certain extent, the analysis of the project networks. For example, by framing my narrative mostly to coincide temporally with my time in the field (within the funding periods of each of the projects), no conclusions can be made about the state of alliances, including new socio-material practices, after I left the field. Additional research

to trace the actor-networks beyond the time frame of the projects' funding, for example, would generate valuable insight into the kinds of 'longer term' socio-material practices that persist (or not) – as well as the trajectories of any technologies developed - and the relationships these might have with broader institutional interdisciplinary programmes, centres and 'ecosystems'. This suggestion will be further discussed in section 8.5 below.

8.3 Re-visiting researcher positionality

Thompson and Rimpiläinen (2012: 1) observe that 'not only are approaches to studying [interdisciplinary] gatherings and heterogeneous processes not well developed, the researcher's toils in this respect are not often evident in ANT accounts'. As such I must re-visit my positionality as a researcher, and in particular as a 'praxiographer', examining how the findings are positioned in relation to my role in the study. 'The interdependency of one's positionality and one's understanding of interdisciplinarity is an issue which has too seldom been explored', comment Lau and Pasquini (2008: 555). Indeed, I have considered this in relation to the researcher-participants across the cases in this study, but I now touch upon it with regards to myself. As I previously disclosed in Chapter 3 (Methodology), I completed a Humanities-based Undergraduate degree, and a Social Science Master's degree. I maintained a personal reflexivity (towards all disciplines) during the entire research process, and was very cognisant of my own potential 'biases' shaped by my educational background, including my own experiences of working in interdisciplinary ways. Hammersley (2000: 12) emphasises that the ethnographer should '…be as neutral as they can towards other values and interests in their work'.

However, as Bogdan and Biklen argue (2007: 38), 'being a clean slate is neither possible nor desirable'. Indeed, Chiseri-Strater (1996: 119) has noted, 'in ethnography a major goal of the research process is self-reflexivity', explaining that this involves locating oneself not only in relation to study participants, but in relation to theory, to methods, and to analysis, among other research components. As an ethnographer drawing from the ANT tradition, it is crucial to note that my own (inter)disciplinary 'ontology' constructed,

translated and inscribed one reality of this study into the words of this thesis – (re)presenting the narratives of the chosen cases.[132] 'Our own stories weave further webs, it is never the case that they simply describe. They too enact realities', explains Law (2009: 154). My praxiography is its own intervention on reality, and I have become entangled in the projects, both through data collection, analysis and narrative presentation. My participation and research practices mediated my own relations with other actors in the project networks across the collective case study. In this way, there is another performance enacted by the steerable needle (CS1), the concept of encoding an epistemology (CS2), and the PhD researcher (CS3), in addition to those throughout the findings chapter: as analytic tokens drawing *my own* material-discursive practices as a doctoral student towards the interdisciplinary project networks. As vu Henry (2018: 258) suggests, being reflexive or 'accountable' as an STS researcher is about being 'responsible for the socio-material relations that are formed through my [own]… practices'. Indeed, I am drawn to the reflection by Baiocchi, Graizbord and Rodríguez-Muñiz (2013: 337):

> 'Ethnography, qualitative research, or indeed any kind of social science, is inescapably a political project in this specific sense. ANT calls for a kind of social science that is neither enchanted nor disenchanted, but one that reflects on its own enchantment… It encourages questions about the kinds of worlds we are helping to make and legitimate in our accounts, and the ways in which we are helping to compose and reconfigure the very communities, processes, and actors under our ethnographic gaze… Ethnographic research acts in and on the world—a fact we must take with great responsibility'

8.4 Some reflections for future practice

Having laid out the contributions of this thesis, and discussing some study limitations as well as my own positionality, I now reflect upon some tentative recommendations for

[132] For example, Geertz's *Works and Lives* (1989) highlighted anthropologists' involvement in co-constructing the world about which they wrote.

future technologically-mediated interdisciplinary practices, particularly for interdisciplinary researchers and other interdisciplinary practitioners (including Universities and funders).

1. It is important for researchers to critically engage with technologies-in-development, particularly within interdisciplinary projects, in order to negate potentially technologically deterministic assumptions. For example, there should be more careful consideration of the ways in which definitions of interdisciplinary success and failure, particularly in relation to technologies-in-development, might be different for different disciplinary researchers.

2. Interdisciplinary teams should participate in meta-cognitive practices. Researchers do not often acknowledge the multiplicity of the 'singular' problem which they are tackling, responding to the 'pressures in the research team to produce a singular account' (Fenwick and Edwards, 2010: 158). Researchers across the interdisciplinary project cases within this thesis might at first have *appeared* to be engaged in a common, single problem (within each case, respectively), but they enacted this in different ways, in particular according to their disciplinary and interdisciplinary 'hinterlands' (Law, 2004). Perceived 'problems' in interdisciplinary practice may be attributed to what was termed 'plurality underlying assumed singularity' by Rimpiläinen (2012: 193). There was also a distinct difference for many of the researchers across the cases between how they thought about interdisciplinarity as quantifiable and dichotomous, that is, through a kind of disciplinary 'black-boxing' (particularly between the 'technical' and 'non-technical'), and how it was practised. Thus, there may be a need for more reflective practices in interdisciplinary research; a form of reflexivity, akin to, but not equal to, commensurability (Kuhn, 1962). Indeed, Adams and Thompson (2014: 7) suggest a need to 'build in' reflective moments as a regular part of ones' research practice: 'Rather than continuing to black-box research tools, techniques, and technologies in their taken-for-granted co-enactment of expert practice,… things themselves must also become sites of explicit inquiry… [and] routines

themselves must be made into an object of enquiry'. Although they do not explicitly discuss interdisciplinarity, their advice is significant according to the findings of this study, as they continue: "The 'closed' technical objects that co-constitute… scientists' habituated research activities must be systematically reflected on as 'open'… Making or 'building in' time for such epistemic as well as ontological reflection is crucial in understanding how materialities… may co-constitute new research practices and co-produce knowledge".

3. Researchers should embrace and explore interdisciplinary tensions, alongside more conventional resolutions and interdisciplinary 'syntheses'. As Callard, Fitzgerald and Woods (2015: 4) found, '…tensions are central to, though frequently disavowed within, interdisciplinary' projects. Researcher's disciplinary 'hinterlands' participate in generating their realities-in-the-making - and thus multiple and divergent research practices (and at times competing interdisciplinarities-in-the-making) - creating resistances, as well as productive frictions. As such, and almost counter-intuitively, it was found that interdisciplinary frictions *are* interdisciplinarity. Relational tensions are the 'matter' of interdisciplinarity, and as such this should be included in practice.

4. University and funding policies around interdisciplinarity in the USA might benefit from reflecting upon the ways in which they evaluate interdisciplinarity. As was established in chapter 2 (Literature Review), there is a 'chronic difficulty in evaluating interdisciplinarity' (Barry and Born, 2013: 39), which, I agree, often falls to the 'disciplinary assessment of… interdisciplinary work' (Mansilla and Gardner, 2003: 151). Barry and Born (2013: 39) also argue that 'interdisciplinarity has a fragile existence due in part to tensions stemming from the submission of interdisciplinary practices to disciplinary evaluation.' As such, this study's findings around the relationships between interdisciplinarity and disciplinarity could offer tentative contributions towards how Higher Education institutions and funding bodies might evaluate technologically-

mediated interdisciplinary research initiatives, with implications for more precisely evaluating interdisciplinary endeavours in the USA.

8.5 Looking ahead: suggestions for further research

Further empirical studies of interdisciplinarity through an ANT lens could build upon this thesis well.[133] In particular, an interesting avenue for future research might focus on digging further into nascent 'inter-disciplines', as I began to do so through the Digital Humanities case (CS2), since according to Leitch (2005), 'the newer postmodern interdisciplinarity respects difference and heterogeneity, proliferating several dozen new inter-disciplines.' Furthermore, this study would be a helpful point of departure to undertake studies of other interdisciplinary projects across, or near to, the interdisciplinary fields which the case projects in this thesis explored; namely Medicine and Engineering (CS1), Humanities and Computer Science/Engineering (broadly, the Digital Humanities) (CS2) and Engineering and the Social Sciences (and other disciplines in the Energy space) (CS3). This would allow further comparisons between enactments of interdisciplinarity within and between these different 'inter-disciplines', adding to the nascent areas of study around each. This could begin to alleviate, for example, Pellegrino and Musy's (2017: 5) concern that 'while recent literature has no hesitation in arguing for interdisciplinary approaches in energy research, very little is still known about how this research should be conducted'. This could also foster exploration into how traditional disciplinary 'hierarchies' and identity politics in institutions might shape interdisciplinary enactments in different ways (Mills and Huber, 2005).

Additionally, it was not possible, given the prescribed scope of this thesis, to conduct an in-depth study of institutional 'effects' on technologically-mediated interdisciplinary research within Higher Education. However, future research would benefit by being more highly contextualised in the wider 'macro-environment' of the University, in this case,

[133] It would also be interesting for future studies to seek other ways to capture the socio-materiality of technologically-mediated interdisciplinarity.

University X. For example, case studies looking into larger scale, interdisciplinary programmes in the USA or the UK (and the projects they support) would prove helpful, and this could tentatively, in turn, have future implications for technology policy and interdisciplinary funding and evaluation within the Higher Education sector globally. Further investigation into the organisational, political and economic factors, in particular in institutions which are traditionally less technologically innovative (or less open to interdisciplinarity across 'traditional' departments and siloes), would also be interesting.

Deeper investigation into interdisciplinary collaborations across institutional borders and organisational boundaries, for example, across different universities and between university and industry would be productive. For example, it would be interesting to develop the discussion point around the 'distributed' nature of interdisciplinarity outside the University within the Energy case (CS3) (where Marco's interdisciplinary agency was in part connected to his relationship with industry). Drawing from the Triple Helix model, in which '…universities, firms and governments assume some of the capabilities of the other, even as each maintains its primary role and distinct identity' (Etzkowitz and Leydesdorff, 1997: 2), further investigation into the Hub, the interdisciplinary research catalyst within which I was based at University X, and their mediation of interdisciplinary spaces between inside and outside (the 'traditional' bounds of) the University - in particular regarding the movement of technologies developed in an academic locale across (disciplinary) boundaries into a commercial setting ('tech transfer') - could complement this study's findings well.

Finally, further investigation into the shaping of technologies developed through interdisciplinary practices by the end users involved, both within Higher Education and within industry, would be interesting. Bjørn and Østerlund (2014: 24) point out that:

> "When we study the practice of designing technology then, at its core, we find the concept of the 'user'… and if we then dive into the conceptualisation of the 'user' it becomes clear that the 'user' is a figuration… created by the designers with the aim

> of getting insights in the 'practices of future use' (Suchman, 2007). However… the 'user' singularises what is actually a multiplicity and fails to differentiate actors with very different relations to a given artefact (Suchman, 2007: 188)…"

Whilst this study did indeed address (interdisciplinary) practice in terms of 'assemblages and entanglements', it would be elucidating to look further into participations of the 'user' in the practices of interdisciplinarity in research projects co-developing new technologies. For example, in the Medical Robotics project (CS1), the clinicians held an interesting 'dual role' as collaborators as well as prospective future users: the radiologists 'are really the end user of the robot I would say' (Jennifer). In the Digital Humanities project (CS2), Nicola was clear to distinguish the disciplinary associations of their 'target user', at one point during a design session worrying that '…we're going to build a tool for designers not Historians if we go too far in this direction!'. The end user, however, was a 'big abstraction' for many of the researchers in the Energy project (CS3). Despite Marco's strong preferences towards (interdisciplinary) engagement with the end-user during technological development, the 'corresponding' disciplinary actors in the social science disciplines - which, if enrolled, would have worked towards enrolling the end-user – resisted. This in part prevented the technologies from 'mobilising' into a commercial environment. As such, it would be particularly interesting to explore further the implications that conceptualising participants as end-users in interdisciplinary projects building new technologies have on enactments of interdisciplinarity. Building upon this point, it would also be interesting to follow (longitudinally) the technologies developed through interdisciplinary projects, looking at if they are taken up and, if so, how they are shaped in practice. Indeed, 'if the artefacts and meanings one seeks to understand don't stand still, why should we as researchers?' (Mills and Morton, 2013: 65).

8.6 Concluding comments

This study has evoked the multiplicity of socio-material practices of technologically-mediated interdisciplinary research in Higher Education in the USA, (un)settling the

'grand narratives' (Welch, 2011: 32) and 'dichotomies' (Graff, 2015: 10) of interdisciplinarity and technology. This thesis holds broad implications for the promotion of advanced conceptual and methodological understandings of modern interdisciplinary practices, and the study lends rich empirical evidence to support the use of methodological and theoretical frameworks from Actor-Network Theory (ANT) in related research in the field of Education/STS. Having critically acknowledged the depth and complexities of the phenomena in practice, positioning technology and conceptualising interdisciplinarity in advanced ways, this work has generated deeper insights into how interdisciplinarity happens in research projects building new technologies. Technologically-mediated interdisciplinarity is a political exercise, and as such 'with each new interdisciplinary venture new forms of coordination need to arise' note Lury et al. (2018: 281). This thesis therefore 'opens up' not only the socio-materiality of technologically-mediated interdisciplinarity, but also future opportunities to explore new interdisciplinarities and technologies as they assemble.

REFERENCES

Abbott A. (2001) *Chaos of Disciplines*. Chicago: University of Chicago Press.

Aboelela, S. W., Larson, E., Bakken, S., Carrasquillo, O., Formicola, A., Glied, S., Haas, J. and Gebbie, K. M. (2007) Defining Interdisciplinary Research: Conclusions from a Critical Review of the Literature. *Health Services Research Journal,* **42** (1), 329–346.

Adams, C. and Thompson, T. (2011) Interviewing objects: including educational technologies as qualitative research participants. *International Journal of Qualitative Studies in Education*, **24** (6), 733–750.

Adams, C. and Thompson, T. (2014) Interviewing the Digital Materialities of Posthuman Inquiry: Decoding the encoding of research practices. [Online]. *Proceedings of the 9th International Conference on Networked Learning*. Available from: https://www.lancaster.ac.uk/fss/organisations/netlc/past/nlc2014/abstracts/pdf/adams.pdf [Accessed 2 February 2019]

Akrich, M. (1992) The de-scription of technical objects. In: W. E. Bijker and J. Law (eds.) *Shaping technology/ building society: Studies in Sociotechnical Change*. MIT Press, 205 – 224.

Akrich, M., Callon, M. and Latour, B. (2002) The key to success in innovation – part II: the art of choosing good spokespersons, *International Journal of Innovation Management*, **6** (2), 207–225.

Akrich, M. and Latour, B. (1992) A Summary of a Convenient Vocabulary for the Semiotics of Human and Nonhuman Assemblies. In: Bijker W. and Law J. (eds.) *Shaping Technology/Building Society*. Cambridge, MA: The MIT Press, 259–264.

Albert, M., Friesen, F., Rowland, P. and Laberge, S. (2019) Problematizing assumptions about interdisciplinary research: implications for health professions education research. *Advances in Health Sciences Education*, 1 -13.

Aldrich J, H. (ed.) (2014) *Interdisciplinarity: Its Role in a Discipline-Based Academy*. Oxford University Press: New York, NY.

Anderson, L. (2008) Reflexivity. In: R. Thorpe and R. Holt (eds.) *The SAGE dictionary of qualitative management research*. London: SAGE Publications, 184 – 186.

Apostel, L., Berger, G., Briggs, A. and Michaud, G. (eds.) (1972) *Interdisciplinarity: Problems of teaching and research in universities*. Paris: Organization for Economic Cooperation and Development.

Aram, J. (2004) Concepts of interdisciplinarity: Configurations of knowledge and action. *Human Relations,* **57** (4), 379–412.

Auerbach, C. and Silverstein, L. (2003) *Qualitative data: An introduction to coding and analysis*. New York: New York University Press.

Augsburg, T. (2016) *Becoming Interdisciplinary: An Introduction to Interdisciplinary Studies*. Kendall Hunt.

Baiocchi, G., Graizbord, D. and Rodríguez-Muñiz, M. (2013) Actor-Network Theory and the ethnographic imagination: An exercise in translation. *Qualitative Sociology*, 36 (4), 323–341.

Balmaceda, M., Högselius, P., Johnson, C., Pleines, H., Rogers, D. and Tynkkynen, V. (2019) Energy materiality: A conceptual review of multi-disciplinary approaches. *Energy Research & Social Science*, 56, 101220.

Barab, S., Schatz, S. and Scheckler, R. (2004) Using Activity Theory to Conceptualize Online Community and Using Online Community to Conceptualize Activity Theory. *Mind, Culture and Activity*, **11** (1), 25 – 47.

Barad, K. (2003) Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. *Journal of Women in Culture and Society*, **28** (3), 801-831.

Barad, K. (2007) *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Duke University Press.

Bardzell, J. and Bardzell, S. (2016) Humanistic HCI. *Interactions,* **23** (2), 20–29.

Baron, L. F. and Gomez, R. (2016) The Associations between Technologies and Societies: The Utility of Actor-Network Theory. *Science, Technology & Society*, **21** (2), 1–20.

Barry, A. (2013) The Translation Zone: Between Actor-Network Theory and International Relations. *Millennium: Journal of International Studies*, **41** (3), 413–429.

Barry, A. and Born, G. (2013) *Interdisciplinarity: reconfigurations of the social and natural sciences*. London: Routledge.

Barry, A., Born, G. and Strathern, M. (2007) Interdisciplinarity and Society: A Critical Comparative Study. ESRC End of Award Report, RES-151-25-0042-A. Swindon: ESRC, 24 – 37.

Barry, A., Born, G. and Weszkalnys, G. (2008) Logics of interdisciplinarity. *Economy and Society*, **37** (1), 20-49.

Barry, A. and Slater, D. (2002) Introduction: the technological economy. *Economy and Society*, **31** (2), 175-193

Bauer, H. H. (1990) Barriers Against Interdisciplinarity: Implications for Studies of Science, Technology, and Society (STS). *Science, Technology, & Human Values*, **15** (1), 105–119.

Becher, T. (1994) The significance of disciplinary differences. *Studies in Higher Education*, **19** (2), 151–161.

Becher, T., and Trowler, P. (2001) *Academic tribes and territories: Intellectual inquiry and the culture of disciplines (2nd ed)*. Buckingham, UK: Open University Press.

Bergman, M. and Coxon, A. (2005) The Quality in Qualitative Methods. *Qualitative Social Research*, 6 (2: 34).

Berry, D. (2011) The Computational Turn: Thinking about the Digital Humanities. *Culture Machine*, 12, 1–22.

Berry, D. (2012) *Understanding Digital Humanities*. London: Springer.

Berry, David (2019) *Critical Digital Humanities*. Technology, AI and Ethics. [Online]. Available from: https://conditiohumana.io/critical-digital-humanities/ [Accessed 14 November 2019]

Berry, D. and Fagerjord, A. (2017) *Digital humanities: knowledge and critique in a digital age*. Malden, MA: Polity Press.

Bezemer, J., Cope, A., Kress, G., and Kneebone, R. (2013) Holding the Scalpel: Achieving Surgical Care in a Learning Environment. *Journal of Contemporary Ethnography*, **43** (1), 38–63.

Biesta, G. (2009) Disciplinarity and Interdisciplinarity in the Academic Study of Education: Comparing Traditions of Educational Theorising. In: Annual Conference of the British Educational Research Association. Manchester, 1-15.

Bijker, W. (1995) *Of Bicycles, Bakelites, and Bulbs. Toward a Theory of Sociotechnical Change*. Cambridge, MA: The MIT Press.

Bijker, W., Hughes, T., and Pinch, T. (1987) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. MIT Press, Cambridge, MA.

Bijker, W and Pinch, T. (2012) The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other. *Social Studies of Science*, **14** (3), 399–441.

Bjørn, P. and Østerlund, C. (2014) *Sociomaterial-Design: Bounding Technologies in Practice*. Springer.

Blackwell, A., Wilson, L., Street, A., Boulton, C. and Knell, J. (2009) Radical innovation: crossing knowledge boundaries with interdisciplinary teams. Innovation and interdisciplinarity, Technical Report 760.

Blok, A., Farias, I. and Roberts, C. (eds.) (2019*) The Routledge Companion to Actor-Network Theory*. Routledge Companions.

Bogdan, R. and Biklen, S. (2007) *Qualitative Research for Education: An Introduction to Theory and Methods*. London: Pearson Education.

Boix Mansilla, V., Lamont, M. and Sato, K. (2016) Shared cognitive-emotional-interactional platforms: markers and conditions for successful interdisciplinary collaborations. *Science, Technology & Human Values*, **41** (4), 571 – 612.

Borgman, C. (2007) *Scholarship in the digital age: Information, infrastructure, and the Internet*. Cambridge, MA: MIT Press.

Bowden, G. (2011) Coming of Age in STS: Some methodological musings. In: S. Jasanoff, G. E. Markle, J. Petersen and T. Pinch (eds.) *Handbook of Science and Technology Studies*. Thousand Oaks, CA: Sage, 64 – 79.

Bowen, G. (2009) Document Analysis as a Qualitative Research Method. *Qualitative Research Journal*, **9** (2), 27-40.

Bowker, G. C. and Star, S. L. (1999) *Sorting Things Out: Classification and Its Consequences*. Cambridge, MA: MIT Press.

Brew, A. (2007) Disciplinary and interdisciplinary affiliations of experienced researchers. *Higher Education*, **56** (4), 423–438.

Brewer, J. (2000) *Ethnography*. Open University Press.

Bridges, D. (2006) The Disciplines and Discipline of Educational Research. *Journal of Philosophy of Education*, **40** (2), 259–272.

Broto, C., Gislason, M. and Ehlers, M. (2009) Practising interdisciplinarity in the interplay between disciplines: experiences of established researchers. *Environmental Science and Policy*, **12** (7), 922-933.

Bruine de Bruin, W. and Granger Morgan, M. (2019) Reflections on an interdisciplinary collaboration to inform public understanding of climate change, mitigation, and impacts. *PNAS*, **116** (16), 7676-7683.

Bryman, A. (2004) *Social Research Methods*. (2nd ed.). Oxford: Oxford University Press.

Buckler, J. A. (2004) Towards a new model of general education at Harvard. [Online]. Available from: http://isites.harvard.edu/fs/docs/icb.topic733185.files/Buckler.pdf [Accessed March 14 2018].

Buller, H. (2008) The lively process of interdisciplinarity. *Area*, **41** (4), 395-403.

Burri, R. V. and Dumit, J. (2008) Social Studies of Scientific Imaging and Visualization. *New Handbook of Science and Technology Studies*, Cambridge, MA. 297–317.

Busch, K. V. (1997) Applying actor-network theory to curricular change in medical schools. *Proceedings of the Annual Midwest Research-to-Practice Conference in Adult, Continuing and Community Education*, 16th, (15–17 October), Michigan State University, 7–12.

Callard, F., Fitzgerald, D. and Woods, A. (2015) Interdisciplinary collaboration in action: tracking the signal, tracing the noise. *Palgrave Communications,* **1** (15019).

Callard, F. and Fitzgerald, D. (2015) Rethinking Interdisciplinarity across the Social Sciences and Neurosciences. *Palgrave Macmillan*.

Callon, M. (1980) Struggles and Negotiations to Define What is Problematic and What is Not. In: Knorr, K., Krohn, R. and Whitley, R. (eds.) *The Social Process of Scientific Investigation: Sociology of the Sciences*, Volume IV, D. Reidel Publishing Company, 197 - 219.

Callon, M. (1986) Some elements of a sociology of translation: domestication of the scallops and the fishermen of St Brieuc Bay. In: J. Law (ed.) *Power, action and belief: a new sociology of knowledge?* London: Routledge and Kegan Paul, 196-223.

Callon, M. (1991) Techno-economic networks and irreversibility. In: Law, J. *A sociology of monsters: essays on power, technology and domination*. London: Routledge, 132–165.

Callon, M. (2001) Actor-Network Theory. In: N. J. Smelser and P. B. Bates. *International Encyclopedia of the Social & Behavioral Sciences*. Amsterdam, Elsevier: 62- 66.

Callon, M. (2007) An Essay on the Growing Contribution of Economic Markets to the Proliferation of the Social. *Theory, Culture & Society*, **24** (7-8), 139-163.

Callon, M. (2012) Society in the making: the study of technology as a tool for sociological analysis. In: W. Bijker, T. Hughes and T. Pinch (eds.) *The Social Construction of Technological Systems*. Cambridge, MA: MIT Press, 77 – 98.

Callon, M. and Law, J. (1982) On interests and their transformation: enrolment and counter-enrolment. *Social Studies of Science,* **12** (4), 615-625.

Carp, R. M. (2001). Integrative praxes: Learning from multiple knowledge formations. *Issues in Integrative Studies*, 19, 71–121.

Carr, G., Loucks, D. P. and Blöschl, G. (2018) Gaining insight into interdisciplinary research and education programmes: A framework for evaluation. *Research Policy*, **47** (1), 35 – 48.

Castells, M. (2004) *The network society: a cross-cultural perspective*. Cheltenham: Edward Elgar Publishing.

Castells, M. (2013) *Communication Power*. Oxford: Oxford University Press.

Chettiparamb, A. (2007) Interdisciplinarity: a literature review. Southampton: The University of Southampton Interdisciplinary Teaching and Learning Group.

Chiseri-Strater, E. (1996) Turning In upon Ourselves: Positionality, Subjectivity, and Reflexivity in Case Study and Ethnographic Research. In: P. Mortensen and G. Kirsch (eds.) *Ethics and Representation in Qualitative Studies of Literacy*. Urbana, Illinois: National Council of Teachers of English, 115–133.

Clough, G., Conole, G. and Scanlon, E. (2010) Using participatory evaluation to support collaboration in an interdisciplinary context. *Proceedings of the seventh international conferences on networked learning*, 3-4 May, Aalborg, Denmark.

Cohen, L. Manion, L. and Morrison, K. (2013) *Research Methods in Education*. Routledge.

Collins, E., Bulger, M., and Meyer, E. (2011) Discipline matters: Technology use in the humanities. *Arts and Humanities in Higher Education*, **11** (1-2), 76-92.

US National Academy of Sciences, National Academy of Engineering, and Institute of Medicine (2005) *Facilitating Interdisciplinary Research. Committee on Facilitating Interdisciplinary Research, Committee on Science, Engineering, and Public Policy*. Washington, DC: National Academies Press.

Conole, G., Scanlon, E., Mundin, P. and Farrow, R. (2010) Technology-enhanced learning as a site for interdisciplinary research. Technology Enhanced Learning Research Programme; Economic and Social Research Council; Institute of Education, London.

Crawford, C. S. (2004) Actor-Network Theory. In: G. Ritzer (ed.) *Encyclopedia of social theory*. Thousand Oaks, CA: Sage, 1 -3.

Cressman, D. (2009) 'A Brief Overview of Actor-Network Theory: Punctualization, Heterogeneous Engineering & Translation', Paper for Simon Frasier University ACT Lab/Centre for Policy Research on Science & Technology (CPROST), 1–17.

Cresswell, K. Worth, A. and Sheikh, A. (2010) Actor-Network Theory and its role in understanding the implementation of information technology developments in healthcare, *BMC Medical Informatics and Decision Making*, **10** (67).

Crow, M. and Dabars, W. B. (2017) Interdisciplinarity and the Institutional Context of Knowledge in the American Research University. In: Frodeman, R., Klein, J. and Pacheco, R. (eds.) *The Oxford Handbook of Interdisciplinarity* (2nd ed.) Oxford: Oxford University Press.

Crowe, S., Cresswell, K., Roberston, A., Huby, G., Avery, A. and Sheikh, A. (2011) The case study approach. *BMC Medical Research Methodology*, 11, 100.

Cummings, J. and Kiesler, S. (2005) Collaborative Research across disciplinary and organisational boundaries. *Social Studies of Science*, **35** (5), 703 – 722.

Davidson, C. N. and Savonick, D. (2017) Digital Humanities: The role of interdisciplinary humanities in the Information Age. In: Frodeman, R., Klein, J. and Pacheco, R. (eds.) *The Oxford Handbook of Interdisciplinarity* (2nd ed.) Oxford: Oxford University Press.

Dankert, R. (2011) Using Actor-Network Theory (ANT) doing research. [Online]. Available from: https://ritskedankert.nl/using-actor-network-theory-ant-doing-research/ [Accessed 5 May 2018]

de Laet, M. and Mol, A. (2000) The Zimbabwe Bush Pump: mechanics of a fluid technology. *Social Studies of Science*, **30** (2), 225 – 263.

Delanty, G. (2001) *Challenging knowledge: the university in the knowledge society*. Open University Press, Buckingham.

Deleuze, G. and Guattari, F. (1980) *A Thousand Plateaus: Capitalism and Schizophrenia*. London: Athlone.

Deleuze, G. and Parnet, C. (2007) *Dialogues II*. Columbia Classics in Philosophy.

Denzin, N. and Lincoln, Y. (eds.) (1994) *Handbook of qualitative research*. London: Sage.

Derrick, E., Falk-Krzesinski, H. and Roberts, M. (eds.) (2011) *Facilitating Interdisciplinary Research and Education: A Practical Guide*. American Association for the Advancement of Science Report.

Desfriches-Doria, O., Sergent, H., Tran, F., Haettich, Y. and Borel, J. (2018) What is Digital Humanities' identity in interdisciplinary practices?: An experiment with digital tools for visualizing the francophone DH network. *Proceedings of the 2nd International Conference on Web Studies,* 39-47.

DesPortes, K., Spells , M. and DiSalvo, B. (2016) Interdisciplinary Computing and the Emergence of Boundary Objects: A Case-Study of Dance and Technology. *International Society of the Learning Sciences,* 890-893.

de Vries, M. J. (2013) Philosophy of Technology. In: P. J. Williams (ed.) *Technology Education for Teachers*. Rotterdam: Sense, 15 – 34.

DeWalt, K. M. and DeWalt, B. R. (2002) *Participant observation: a guide for fieldworkers*. Walnut Creek, CA: Altamira Press.

Donaldson, A., Ward, N. and Bradley, S. (2010) Mess among disciplines: interdisciplinarity in environmental research. *Environment and Planning,* **42** (7), 1521-1536.

Drucker, J. (2012) Humanistic theory and digital scholarship. In: M. K. Gold (ed.) *Debates in the Digital Humanities*. University of Minnesota Press, 85 – 95.

Dutton, W. and Jeffreys, P. (2010) *World Wide Research: Reshaping the Sciences and Humanities*. Cambridge, MA: MIT Press.

Eddy, S. R. (2005) 'Antedisciplinary' Science, *PLoS Computational Biology,* 1 (1), e6.

Elder-Vass, D. (2019) Actor-network theory. In: *The SAGE Encyclopedia of Research Methods*. Sage.

Elger, T. (2010) Bounding the Case. In: Mills, A., Durepos, G. and Wiebe, E. *Encyclopedia of Case Study Research*. Thousand Oaks: Sage Publications.

Elsayad, S. (2016) The Case of Case Study Methodology. *NSBM Journal of Management*, **2** (2), 90–106.

Engeström, Y. (1987) *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki: Orienta-Konsultit Oy.

Enriquez, J. (2009) From Bush Pump to Blackboard: the fluid workings of a virtual environment. *E-Learning and Digital Media*, 6, 385–399.

Ericsson, K. and Simon, H. (1993) *Protocol Analysis: Verbal Reports as Data (2nd ed.)*. Boston: MIT Press.

Etzkowitz, H. and Leydesdorff, L. (1997) *Universities in the global economy: a triple helix of university industry government relations*. London: Cassell.

Feenberg, A. (1999) *Questioning Technology*. London/New York: Routledge.

Fenwick, T. J. and Edwards, R. (2010) *Actor-network theory in education*. Abingdon: Routledge.

Fenwick, T. J. and Edwards, R. (eds.) (2018) *Revisiting actor-network theory in education*. Oxon: Routledge.

Fenwick, T., Edwards, R. and Sawchuk, P. (2011) *Emerging Approaches to Educational Research: Tracing the sociomaterial*. London/New York: Routledge.

Fenwick, T. and Landri, P. (eds.) (2014) *Materialities, Textures and Pedagogies*. London/New York: Routledge.

Fetterman, D. (1998) *Ethnography step-by-step*. SAGE publications.

Fiore, S. M. (2008) Interdisciplinarity as teamwork: How the science of teams can inform team science. *Small Group Research*, 39, 251–277.

Flick, U. (1998) *An Introduction to Qualitative Research*. London: Sage.

Flyvbjerg, B. (2006) Five Misunderstandings About Case-Study Research, *Qualitative Inquiry*, **12** (2), 219–245.

Foshay, R. (ed.) (2011) *Valences of Interdisciplinarity: Theory, Practice, Pedagogy*. AU Press: Athabasca University.

Foucault, M. (1972) *The Archaeology of Knowledge*. London: Tavistock.

Foucault, M. (1977) *Discipline and Punish: The Birth of the Prison*. London: Penguin.

Foucault, M. (1980) 'Body/Power' and 'Truth and Power'. In: C. Gordon (ed.) *Michel Foucault: Power/Knowledge*. London: Harvester.

Frickel, S., Albert, M. and Prainsack, B. (eds.) (2017) *Investigating interdisciplinary collaboration: theory and practice across disciplines*. New Brunswick, NJ: Rutgers University Press.

Friesen, N. (2009) *Re-Thinking E-Learning Research: Foundations, Methods and Practices*. New York: Peter Lang.

Frodeman, R. (2010) Introduction. In: Frodeman, R., Klein, J. and Mitcham, C. (eds.) (2010) *The Oxford Handbook of Interdisciplinarity* (1st ed.) Oxford: Oxford University Press.

Frodeman, R. (2017) The Future of Interdisciplinarity. In: Frodeman, R., Klein, J. and Pacheco, R. (eds.) (2017) *The Oxford Handbook of Interdisciplinarity (2nd ed.)* Oxford: Oxford University Press.

Frodeman, R., Klein, J. and Mitcham, C. (eds.) (2010) *The Oxford Handbook of Interdisciplinarity (1st ed.)* Oxford: Oxford University Press.

Frodeman, R., Klein, J. and Pacheco, R. (eds.) (2017) *The Oxford Handbook of Interdisciplinarity* (2nd ed.). Oxford: Oxford University Press.

Fry, J. (2004) The cultural shaping of ICTs within academic fields: corpus-based linguistics as a case study. *Literary and Linguistic Computing*, **19** (3), 303 – 319.

Fry, J. and Schroeder, R. (2010) The Changing Disciplinary Landscapes of Research. In: W. Dutton and P. Jeffreys (eds.) *World Wide Research: Reshaping the Sciences and Humanities*. Cambridge, MA: MIT Press, 251 – 271.

Fry, J. and Talja, S. (2007) The intellectual and social organization of academic fields and the shaping of digital resources. *Journal of Information Science*, **33** (2), 115-133.

Galison, P. (1997) *Image and Logic: A Material Culture of Microphysics*. Chicago: The University of Chicago Press.

Gaskell, J. and Hepburn, G. (1998) The course as a token: A Construction of/by Networks. *Research in Science Education*, **28** (1), 65-76.

Geertz, C. (1973) *The Interpretation of Cultures*. New York: Basic Books.

Geertz, C. (1989) *Works and Lives: The Anthropologist as Author*. Polity Press.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994) *The New Production of Knowledge: the dynamics of science and research in contemporary societies*. London: Sage Publications.

Gillham, B. (2000) *Case Study Research Methods*. London: Continuum.

Given, L. (2008) *The SAGE Encyclopedia of Qualitative Research Methods*. SAGE.

Gleed, A. and Marchant, D. (2016) Interdisciplinarity: Survey Report for the Global Research Council 2016. [Online]. Available from: https://www.globalresearchcouncil.org/fileadmin/documents/GRC_Publications/Interdisciplinarity_Report_for_GRC_DJS_Research.pdf [Accessed 10 September 2019]

Goddard, T. (2010) Collective Case Study. In: Mills, A., Durepos, G. and Wiebe, E. *Encyclopedia of Case Study Research*. Thousand Oaks: Sage Publications.

Gold, R. (1958) Roles in sociological field observations. *Social Forces*, 36, 217–23.

Gold, M. and Klein, L. (eds.) (2016) Debates in the Digital Humanities 2016. *University of Minnesota Press*.

Gorman, M. (2004) Collaborating on convergent technologies: Education and practice. *Annals of the New York Academy of Sciences,* 1013, 25 – 37.

Gorman, M., Groves, J. and Shrager, J. (2004) *Societal dimensions of nanotechnology as a trading zone: results from a pilot project*. Amsterdam, IOS Press.

Gorur, R. (2011) ANT on the PISA trail: Following the statistical pursuit of certainty. *Educational Philosophy and Theory*, 43(S1), 76 – 93.

Gorur, R., Hamilton, M., Lundahl, C. and Sundström Sjödin, E. (2019) Politics by other means? STS and research in education. *Discourse: Studies in the Cultural Politics of Education*, **40** (1), 1 – 15.

Graff, H. J. (2015) *Undisciplining Knowledge: Interdisciplinarity in the Twentieth Century*. Johns Hopkins University Press.

Graham, M. and Dutton, W. (2014) *Society and the Internet: How Networks of information and communication are changing our lives*. Oxford: Oxford University Press.

Hackett, E., Amsterdamska, O., Lynch, M. and Wajcman, J. (eds.) (2008) *The Handbook of Science and Technology Studies (3rd ed)*. Cambridge: The MIT Press.

Hacking, I. (1986) Making up people. In: T. Heller, M. Sosna, and D. Wellbery (eds.) *Reconstructing Individualism: Autonomy, Individuality, and the Self in Western Thought*. Stanford: Stanford University Press.

Hammersley, M. (2000) *Taking sides in social research: Essays on partisanship and bias*. Routledge.

Hammersley, M. (2007) The issue of quality in qualitative research. *International Journal of Research and Method in Education*, **30** (3), 287–305.

Hammersley, M. and Atkinson, P. (1983) *Ethnography: Principles in Practice*. London: Routledge.

Hammersley, M. and Atkinson, P. (2007) *Ethnography Principles in Practice* (3rd ed.). London: Routledge.

Haraway, D. (1991), 'A Cyborg Manifesto: Science, Technology and Socialist Feminism in the Late Twentieth Century'. In: D, Haraway (ed.) *Simians, Cyborgs and Women: The Reinvention of Nature*. London: Free Association Books, 149–181.

Haraway, D. (2000) *How like a leaf*. Routledge, London.

Hargreaves, T. and Burgess, J. (2009) Pathways to Interdisciplinarity: A technical report exploring collaborative interdisciplinary working in the Transition Pathways consortium. [Online]. Available from: http://www.cserge.ac.uk/sites/default/files/edm_2010_12.pdf [Accessed 15 May 2016].

Harman, G. (2009) *Prince of networks: Bruno Latour and metaphysics*. Melbourne: Anamnesis.

Hartley, J. (2004) Case study research. In: C. Catherine and G. Symon (eds.) *Essential guide to qualitative methods in organizational research*. London: Sage, 323-333.

Hassard, B. and Alcadipani, R. (2010) Actor-Network Theory. In: A. Mills, G. Eurepos and E. Wiebe (eds.) *Encyclopedia of Case Study Research,* 8–12.

Haythornthwaite, C. (2006) Learning and Knowledge Networks in Interdisciplinary Collaborations. *Journal of the American Society for Information Science and Technology*, **57** (8), 1079-1092.

Haythornthwaite, C., Lunsford, K., Bowker, G., and Bruce, B. (2006) Challenges for Research and Practice in Distributed, Interdisciplinary Collaboration. In: C. Hine (ed.) *New Infrastructures for Knowledge Production*. Idea Group Inc., 143-167.

Hermann, F., Rummel, N., and Spada, H. (1998) Solving the Case together: The challenge of Net-based interdisciplinary collaboration. In: P. Dillenbourg et al. (eds.) *Proceedings of the First European Conference on Computer-Supported Collaborative Learning*. Maastricht: McLuhan Institute, 293 – 300.

Hidayanto, A. and Setyady, S. (2014) Impact of collaborative tools utilisation on group performance in university students. *TOJET: The Turkish Online Journal of Educational Technology*, **13** (2), 88 – 98.

Holley, K. (2009) Understanding interdisciplinary challenges and opportunities in higher education. *Innovations in Higher Education,* 34, 1-131.

Houghton, J., Steele, C. and Henry, M. (2004) Research practices and scholarly communication in the digital environment. *Learned Publishing*, **17** (1), 231-249.

Howe, K. and Moses, M. (1999) Ethics in educational research. *Review of Research in Education,* 24, 21-60.

Huber, M. and Morreale, S. (eds.) (2002) *Disciplinary Styles in the Scholarship of Teaching and Learning: Exploring Common Ground*. Washington D.C.: American Association for Higher Education and The Carnegie Foundation for the Advancement of Teaching.

Huutoniemi, K., Klein, J., Bruun, H. and Hukkinen, J. (2010) Analyzing interdisciplinarity: Typology and indicators. *Research Policy,* **39** (1), 79-88.

Hvidtfeldt, R. (2018) *The Structure of Interdisciplinary Science*. New Directions in the Philosophy of Science. Palgrave Macmillan.

'Inventing Indicators of Interdisciplinarity' (2019) Inventing Indicators of Interdisciplinarity. Warwick Centre for Interdisciplinary Methodologies. [Online]. Available from: https://warwick.ac.uk/fac/cross_fac/cim/research/inventing-indicators-of-interdisciplinarity/ [Accessed 28 November 2019]

Irani, Z. (2018) The university of the future will be interdisciplinary. The Guardian, 24 January.

Jacobs, J. (2009) Interdisciplinary Hype. *The Chronicle of Higher Education. The Chronicle Review* (November 22). Available at: https://www.chronicle.com/article/Interdisciplinary-Hype/49191 [Accessed: 10 November 2019]

Jacobs, J. (2013) *In Defence of Disciplines: Interdisciplinarity and Specialization in the Research University*. The University of Chicago Press.

Jacobs, J. and Frickel, S. (2009) Interdisciplinarity: A Critical Assessment. *Annual Review of Sociology*, 35, 43 – 65.

Jänicke, S., Franzini, G., Cheema, M. and Scheuerman, G. (2015) On Close and Distant Reading in Digital Humanities: A Survey and Future Challenges. Eurographics Conference on Visualization (EuroVis, 2015).

Jasanoff, S. (2004) *States of Knowledge: The Co-Production of Science and the Social Order*. Routledge: Taylor & Francis Group.

Jasanoff, S. (2016) *The Ethics of Invention: Technology and the Human Future*. Norton & Company.

Jasanoff, S. and Kim, S. (2015) *Dreamscapes of Modernity: Sociotechnical imaginaries and the fabrication of power*. The University of Chicago.

Jordan, K. and Rimpiläinen, S. (2010) The many faces and phases of the Semantic Spider. Paper presented at the 2010 EASST Conference. University of Trento, Italy, (3 September).

Kirschenbaum, M. (2014) What Is 'Digital Humanities' and Why Are They Saying Such Terrible Things about It? In: In the Shadows of the Digital Humanities, *differences 25.1*.

Klein, J. (1990) *Interdisciplinarity: History, Theory, and Practice*. Detroit: Wayne State University.

Klein, J. (1996) *Crossing boundaries: Knowledge, disciplinarities, and interdisciplinarities*. Charlottesville, VA: University of Virginia Press.

Klein, J. (2001) Interdisciplinarity and the prospect of complexity: The tests of a theory. *Issues in Integrative Studies*, 19, 1-25.

Klein, J. (2004) Interdisciplinarity and complexity: An evolving relationship. *E:CO Special Double*. 6 (1-2), 2-10.

Klein, J. (2008) Evaluation of interdisciplinary and transdisciplinary research: a literature review. *American journal of preventive medicine,* 35(2 Suppl), 116-123.

Klein, J. (2015) *Interdisciplining Digital Humanities: Boundary Work in an Emerging Field*. University of Michigan Press.

Klein, J. (2017) Typologies of Interdisciplinarity: The Boundary Work of Definition. In: Frodeman, R., Klein, J. and Pacheco, R. (eds.) (2017) *The Oxford Handbook of Interdisciplinarity (2nd ed)*. Oxford: Oxford University Press.

Klein, J. and Newell, W. (1997) Advancing interdisciplinary studies. In: J. Gaff and J. Ratcliffe (eds.) *Handbook of the undergraduate curriculum: A comprehensive guide to purposes, structures, practices, and changes.* San Francisco: Jossey-Bass, 393-415.

Klevorick, A., Levin, R., Nelson, R. and Winter, S. (1995) On the sources and significance of inter-industry differences in technological opportunities. *Research Policy,* 24, 185-205.

Kling, R., McKim, G. and King, A. (2003) A bit more to IT: scholarly communication forums as socio-technical interaction networks. *Journal of the American Society for Information Science and Technology*, **54** (1), 47–67.

Knorr-Cetina, K. (1981) *The Manufacture of Knowledge. An Essay on the Constructivist and Contextual Nature of Science*. Oxford, Pergamon Press.

Knorr-Cetina, K. (1999) *Epistemic Cultures: How the Sciences Make Knowledge*. Cambridge, MA: Harvard University Press.

Knorr-Cetina, K. (2008) Objectual practice. In: M, Mazzotti (Ed.) *Knowledge as social order: Rethinking the sociology of Barry Barnes*. Hampshire, UK: Ashgate, 83-98.

Kockelmans, J. J. (1979) *Interdisciplinarity and Higher Education*. University Park: The Pennsylvania State University Press.

Koski, L. (2011) Interdisciplinarity in the context of University Politics. *European Educational Research Journal,* 10 (1). EERJ roundtable at ECER, Helsinki, Finland.

Kramnick, J. (2018) The Interdisciplinary Delusion. *The Chronicle of Higher Education* (11 October) [Online]. Available at: https://www.chronicle.com/article/The-Interdisciplinary-Delusion/244772 [Accessed: 4 March 2019].

Krippendorff, K. (2004). *Content Analysis: An Introduction to its methodology*. Thousand Oaks, CA: Sage.

Krishnan, A. (2009) What are academic disciplines? Some observations on the Disciplinarity vs. Interdisciplinarity debate. ESRC National Centre for Research Methods, 57.

Kuhn, T. (1962) *The Structure of Scientific Revolutions*. University of Chicago Press.

Kuhn, T. (1982) Commensurability, Comparability, Communicability. *PSA: Proceedings of the Biennial Meeting of the Philosophy of Science Association,* 2, 669-688.

Kuutti, K. (1996) Activity theory as a potential framework for human-computer interaction research. In: B. A. Nardi (ed.) *Context and consciousness: Activity theory and human-computer interaction,* 17 – 44.

Kvale, S. (1996) *Inter Views: An Introduction to Qualitative Research Interviewing*, Thousand Oaks, CA: Sage.

Lakhani, J., Benzies , K. and Hayden, K. A. (2012) Attributes of Interdisciplinary Research Teams: A Comprehensive Review of the Literature. *Clinical and investigative medicine*, 35 (5):E226.

Langemeyer, I. and Roth, M. (2006) Is cultural-historical activity theory threatened to fall short of its own principles and possibilities as a dialectical social science? *Critical Social Studies*. 3, 20–42.

Langmead, A., Otis, J., Warren, C., Weingart, S. and L. Zilinski (2016) Towards Interoperable Network Ontologies for the Digital Humanities, *International Journal of Humanities and Arts Computing*, **10** (1), 22–35.

Latour, B. (1987) *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press.

Latour, B. (1993) *We Have Never Been Modern*. Harlow: Pearson Education.

Latour, B. (1996) On actor-network theory: A few clarifications. *Soziale Welt 47. Jahrg.*, H. 4, 369-381.

Latour, B. (1999) On Recalling ANT, *The Sociological Review*, 47, 15–25.

Latour, B. (2005) *Reassembling the Social: an introduction to actor-network theory*. Oxford: Oxford University Press.

Latour, B. (2012) Paris, Invisible City: The Plasma. *City, Culture and Society*, **3** (2), 91–93.

Latour, B. and Woolgar, S. (1979) *Laboratory Life*. Chichester: Princeton University Press.

Latour, B. and Woolgar, S. (1986) *Laboratory Life: The Construction of Scientific Facts*. Princeton, NJ: Princeton University Press.

Lattuca, L. (2002) Learning Interdisciplinarity: Sociocultural Perspectives on Academic Work. *The Journal of Higher Education*, **73** (6), 711-739.

Lau, L. and Pasquini, M. (2008) 'Jack of all trades'? The negotiation of interdisciplinarity within geography. *Geoforum,* **39** (2), 552-560.

Lave, J. and Wenger, E. (1991) *Situated learning: legitimate peripheral participation*. Cambridge, Cambridge University Press.

Law, J. (1989) Technology and Heterogenous Engineering: The Case of Portuguese Expansion. In: Bijker, W., Hughes, T., and Pinch, T. (eds.) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. MIT Press, Cambridge, MA, 111 – 134.

Law, J. (1992) Notes on the theory of the actor-network: ordering, strategy, and heterogeneity. *Systemic Practice and Action Research,* **5** (4), 379–93.

Law, J. (1999) After ANT: complexity, naming and topology. In: J. Law and J. Hassard (eds.) *Actor Network Theory and after*. Oxford: Blackwell Publishing.

Law, J. (2002) *Aircraft Stories: Decentering the Object in Technoscience*. Durham, North Carolina: Duke University Press.

Law, J. (2004) *After Method: mess in social science research*. London: Routledge.

Law, J. (2007) Making a mess with method. In: W. Outhwaite and S. P. Turner (eds.) *The Sage Handbook of Social Science Methodology*, London and Beverly Hills: Sage, 595–606.

Law, J. (2009) Actor network theory and material semiotics. In: B.S. Turner (ed.) *The New Blackwell Companion to Social Theory*. Chichester: Wiley-Blackwell, 141-158.

Law, J. and Hassard, J. (eds.) (1999) *Actor Network Theory and after*. Oxford: Blackwell Publishing.

Law, J. and Hetherington, K. (2000) Materialities, Spatialities, Globalities. In: J. Bryson, P. Daniels, N. Henry and J. Pollard (eds.) *Knowledge, Space, Economy*. London, UK: Routledge, 34–49.

Law, J. and Lien, M. (2012) Slippery: Field notes in empirical ontology. *Social Studies of Science,* 43 (3), 363 – 378.

Law, J. and Mol, A. (2002) *Complexities: Social Studies of Knowledge Practices*. Durham: Duke University Press.

Law, J. and Singleton, V. (2005) Object Lessons. *Organization*, **12** (3), 331–355.

Law J. and Singleton V. (2013) ANT and politics: working in and on the world. *Qualitative Sociology*, **36** (4), 485–502.

Layder, D. (1998) *Sociological practice: Linking theory and research*. London: Sage.

Layton, E. (1977) Conditions of Technological Development. In: I. Spiegel-Rosing and D. J. deSolla Price (eds.) *Science, Technology, and Society*. London and Beverly Hills, California: Sage.

LeCompte, M. and Preissle, J. (1993) *Ethnography and Qualitative Design in Educational Research*. New York: Academic Press.

Ledford, H. (2015) How to solve the world's biggest problems. (16 September). [Online] Available from: https://www.nature.com/news/how-to-solve-the-world-s-biggest-problems-1.18367 [Accessed 16 August 2019]

Leitch, V. (2000) Postmodern Interdisciplinarity. *Modern Language Association, Profession*, 124-131.

Leitch, V. (2005) Interview. *Interculture*. [Online]. Available from: www.fsu.edu/~proghum/interculture/VB%20Interview.htm [Accessed 12 September 2016].

LERU (2016) Interdisciplinarity and the 21st century research-intensive university. LERU Office.

Lezaun, J. (2017) Actor-Network Theory, *Social Theory Now,* 1–36.

Lin, Y. (2012) Transdisciplinarity and digital humanities: Lessons learned from developing text-mining tools for textual analysis. *Understanding Digital Humanities*, 295–314.

Liu, A. (2009) Digital Humanities and Academic Change. *English Language Notes,* 47, 17-35.

Lury, C. (2018) Introduction. In: Lury, C., Fensham, R., Heller-Nicholas, A., Lammes, S., Last, A., Michael, M. and Uprichard, E. (eds.) *Routledge Handbook of Interdisciplinary Research Methods.* Routledge International Handbooks.

Lury, C., Fensham, R., Heller-Nicholas, A., Lammes, S., Last, A., Michael, M. and Uprichard, E. (eds.) (2018) *Routledge Handbook of Interdisciplinary Research Methods.* Routledge International Handbooks.

Lyall, C., Bruce, A., Tait, J. and Meagher, L. (2011) *Interdisciplinary Research Journeys: Practical Strategies for Capturing Creativity*. Bloomsbury.

Lyall, C. (2019) *Being an Interdisciplinary Academic: How Institutions Shape University Careers*. Palgrave Macmillan.

Lynch, M. (1991) Laboratory space and the technological complex: An investigation of topical contextures. *Science in Context*, **4** (1), 51–78.

Lyotard, J. (1984) *The Postmodern Condition: a report on knowledge* (trans. G. Bennington and B. Massumi). Minneapolis: University of Minnesota Press. (Original 1979).

MacKenzie, D. and Wajcman, J. (eds.) (1985) *The social shaping of technology: how the refrigerator got its hum*. Milton Keynes: Open University Press.

MacLeod, M. and Nagatsu, M. (2018) What does interdisciplinarity look like in practice: Mapping interdisciplinarity and its limits in the environmental sciences. *Studies in History and Philosophy of Science*, 67, 74-84.

Mäki, U. and MacLeod, M. (2016) Interdisciplinarity in action: philosophy of science perspectives. *European Journal for Philosophy of Science,* 6 (3), 323-326.

Mansilla, V. and Gardner, H. (2003) Assessing Interdisciplinary Work at the Frontier: An empirical exploration of 'symptoms of quality'. GoodWork Project Report Series, Number 26.

Martin, B. (1998) *Information Liberation.* London: Freedom Press.

Massey, D. (1991) A global sense of place. *Marxism Today,* **35** (6), 24–29.

Mattila, E. (2005) Interdisciplinarity 'In the Making': Modelling Infectious Diseases. *Perspectives on Science*, **13** (4), 531-53.

May, T. (2001) *Interviewing: methods and process. In: Social Research: Issues, methods and process*. Buckingham: Open University Press, 120 -145.

Mayer, K., Wöhrer, V. and Stöckelová, T. (2008) Acting with Social Sciences and Humanities. Acting with Science, Technology and Medicine. At: International 4S

conference organized by Society for Studies of Science and European Association for the Study of Science and Technology (EASST). Rotterdam, the Netherlands.

McDougall, A., Goldszmidt, M., Kinsella, E., Smith, S. and Lingard, L. (2016) Collaboration and entanglement: An actor-network theory analysis of team-based intraprofessional care for patients with advanced heart failure, *Social Science & Medicine*, 164, 108–117.

McGregor, J. (2004) Spatiality and the place of materiality in schools. *Pedagogy, Culture and Society,* **12** (3), 347 – 372.

McMurtry, A. (2013) Interdisciplinary and Collaboration Through the Lens of Collective and Sociomaterial. *Issues in Interdisciplinary Studies*, **98** (31), 75–98.

Meyer, C. (2001) A case in case study methodology. *Field methods*, **13** (4), 329 – 352.

Meyer, E. (2006) Socio-Technical Interaction Networks: A discussion of the strengths, weaknesses and future of Kling's STIN model. In: Pruulmann-Vengerfeldt, P., Social Informatics: An Information Society for all? In Remembrance of Rob Kling. *IFIP International Federation for Information Processing*, 223, 459–468.

Meyer, E. (2007) Socio-Technical Perspectives on Digital Photography: Scientific Digital Photography Use by Marine Mammal Researchers (PhD). September, 1–355.

Meyer, E. and Schroeder, R. (2015) *Knowledge Machines: Digital Transformations of the Sciences and Humanities*. Cambridge, MA: MIT Press.

Michael, M. (2017) *Actor-Network Theory: Trials, Trails and Translations*. London/New York: Sage.

Miettinen, R. (1999) The riddle of things: Activity Theory and Actor-Network as approaches to studying innovations. *Mind, Culture and Activity*, **6** (3), 170-195.

Miles, M. and Huberman, A. (1994) *Qualitative data analysis: an expanded sourcebook* (2nd ed.) London: Sage.

Miles, M. and Rainbird, S. (2014) Evaluating interdisciplinary collaborative learning and assessment in the creative arts and humanities. *Arts and Humanities in Higher Education*, **14** (4), 409-425.

Mills, A., Durepos, G. and Wiebe, E. (2010) *Encyclopedia of Case Study Research*. Thousand Oaks: Sage Publications.

Mills, D. (2013) Related Disciplines. In: J. Carrier and D. Gewertz (eds.) *The Handbook of Sociocultural Anthropology*. Bloomsbury.

Mills, D. and Huber, M. (2005) Anthropology and the Educational 'Trading Zone': Disciplinarity, pedagogy and professionalism. *Arts and Humanities in Education,* **4** (1), 9-32.

Mills, D. and Morton, M. (2013) *Ethnography in Education*. BERA/SAGE Research Methods in Education.

Mitchell, B. (2017) Thinking of the actor-network theory interview: Who/what/why are you interviewing? (4 April). ProPEL Matters [Online]. Available from:

https://propelmatters.stir.ac.uk/2017/04/04/thinking-of-the-actor-network-theory-interview-whowhatwhy-are-you-interviewing/ [Accessed 4 October 2017]

Mol, A. (1999) Ontological politics A word and some questions. In: J. Law and J. Hassard (eds.) *Actor network theory and after*. Oxford & Malden, MA, 74-89

Mol, A. (2002) *The Body Multiple: Ontology in medical practice*. Durham: Duke University Press.

Mol, A. (2010) Actor-Network Theory: sensitive terms and enduring tensions. *Kölner Zeitschrift für Soziologie und Sozialpsychologie*. Sonderheft, 50, 253-269.

Monteiro, E. and Hanseth, O. (1996) Social Shaping of Information Infrastructure: On Being Specific about the Technology. In: W. J. Orlikowski, G. Walsharn, M. R Jones, and J. I. DeGross (eds.) *Information Technology and Changes in Organizational Work*. London: Chapman & Hall.

Monteiro, M. (2018) Ethnography and interdisciplinary work: experiences from the US and Brazil. *Tapuya: Latin American Science, Technology and Society,* 153 – 169.

Monteiro, M. and Keating, E. (2009) Managing Misunderstandings: The Role of Language in Interdisciplinary Scientific Collaboration. *Science Communication,* 31 (1), 6 – 28.

Moran, J. (2002) *Interdisciplinarity (1st ed)*. Routledge: Oxon.

Moreira, T. (2006) Heterogeneity and coordination of blood pressure in neurosurgery, *Social Studies of Science*, **36** (1), 69–97.

Morrison, K. R. B. (1993) *Planning and Accomplishing School-centred Evaluation*. Norfolk: Peter Francis.

Mulcahy, D. (2006) The salience of space for pedagogy and identity in teacher education: problem-based learning as a case in point. *Pedagogy, Culture and Society*, **14** (1), 55- 69.

Mulcahy, D. (2013) Doing interdisciplinary knowledge work within higher education: A relational materialist perspective. *Eighth International Conference on Researching Work and Learning (RWL8),* Stirling, Scotland.

Müller, R. and Kaltenbrunner, W. (2019) Re-disciplining Academic Careers? Interdisciplinary Practice and Career Development in a Swedish Environmental Sciences Research Center. *Minerva,* 57, 479–499.

Müller, M. and Schurr, C. (2016) Assemblage thinking and actor-network theory: conjunctions, disjunctions, cross-fertilisations. *Transactions of the Institute of British Geographers,* 41 (3), 217 – 229.

Nancarrow, S., Booth, A., Ariss, S., Smith, T., Enderby, P. and Roots, A. (2013) Ten principles of good interdisciplinary team work. *Human Resources for Health,* 11 (19).

Naus, J. (2017) The Social Dynamics of Smart Grids On Households, Information flows and Sustainable Energy Transitions (PhD), Wageningen University.

Nespor, J. (1994) *Knowledge in Motion: Space, time and curriculum in undergraduate physics*. London: Routledge.

Newell, W. H. (2001) A Theory of Interdisciplinary Studies. *Issues in Integrative Studies,* 19, 1-25.

Ng, B., Yap, K. and Hoh, Y. (2011) Students' Perception of Interdisciplinary, Problem-Based Learning in a Food Biotechnology Course. *Journal of Food Science Education,* 10 (1), 4-8.

Nimmo, R. (2011) Actor-Network Theory and Methodology: Social Research in a More-Than-Human World', *Methodological Innovations Online*, **6** (3), 108–119.

Nimmo, R. (2016) Introduction: From Generalised Symmetry to Ontological Politics and After - Tracing Actor-Network Theory. In: R. Nimmo (ed.) *Actor-Network Theory Research*, Four Volume Set.

Nowotny, H., Scott, P. and Gibbons, M (2001) *Re-thinking Science: Knowledge and the public in an age of uncertainty*. Cambridge: Polity Press.

Nowotny, H., Scott, P. and Gibbons, M. (2003) Mode 2 Revisited: The New Production of Knowledge. *Minerva*, 41, 179-194.

Oliver, M. (2005) The Problem with Affordance. *E-Learning*, **2** (4), 402 – 413.

Oliver, M. (2011) Technological determinism in educational technology research: some alternative ways of thinking. *Journal of Computer Assisted Leaning,* 27, 373-384.

Oliver, M. (2012) Learning with technology as coordinated sociomaterial practice: digital literacies as a site of praxiological study. In: *Proceedings of the 8th International Conference on Networked Learning*, 440 – 447. Available from: http://www.lancaster.ac.uk/fss/organisations/netlc/past/nlc2012/abstracts/pdf/oliver.pdf [Accessed 14 March 2018]

Oliver, M. (2013) Learning technology: Theorising the tools we study. *British Journal of Educational Technology,* **44** (1), 31 – 43.

Oliver, M. (2016) What is technology? In: Rushby, N. and Surry, D. (eds.) *The Wiley Handbook of Learning Technology*. Wiley Handbooks in Education.

Olson, M. (2009) Robotic Surgery, Human Fallibility, and the Politics of Care. PhD, University of North Carolina at Chapel Hill. Available from: https://cdr.lib.unc.edu/indexablecontent/uuid:bac15651-05f4-4547-a9ad-cee9794fa3ae [Accessed 4 July 2017]

O'Rourke, M., Crowley, S., Eigenbrode, D., and Wulfhorst, J. (2014) *Enhancing Communication and Collaboration in Interdisciplinary Research*. Faculty Authored Books. Book 383.

Osborne, P., Sanford, S. and Alliez, E. (2015) Problematizing Disciplinarity, Transdisciplinary Problematics. *Theory, Culture & Society,* 32 (5-6), 3-35.

Palmer, C. and Cragin, M. (2008) Scholarship and disciplinary practices. *Annual Review of Information Science and Technology,* **42** (1), 163 – 212.

Patton, M. (1990) *Qualitative evaluation and research methods* (2nd ed). Newbury Park, CA: Sage.

Payne, L. (1999) Interdisciplinarity: Potentials and Challenges. *Systemic Practice and Action Research*, **12** (2), 173-182.

Pea, R. (1993) Practices of distributed intelligence and designs for education. In: G. Saloman. *Distributed cognitions: Psychological and educational considerations*. Cambridge University Press, 17 -87.

Pellegrino, M. and Musy, M. (2017) Seven questions around interdisciplinarity in energy research. *Energy Research and Social Science,* 32 (July), 1–12.

Piaget, J. (1972) *The Epistemology of Interdisciplinary Relationships*. Paris: Organization for Economic Cooperation and Development (OECD).

Pickering, A. (2013) Ontology and antidisciplinarity. In: A. Barry and G. Born (eds.) *Interdisciplinarity: reconfigurations of the social and natural sciences*. London: Routledge, 209–225.

Pinch, T. (1990) The culture of scientists and disciplinary rhetoric. *European Journal of Education,* **25** (3), 295 – 304.

Pinch, T. and Bijker, W. (1984) The social construction of facts and artefacts: or how the sociology of science and the sociology of technology might benefit each other. *Social Studies of Science,* **14**(3), 399-441.

Porter, A. L. and Rafols, I. (2009) Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, **81** (3), 719 – 745.

Porter, A. L., Roessner, J. D., Cohen, A. S. and Perreault, M. (2006) Interdisciplinary research: meaning, metrics and nurture. *Research Evaluation*, **15** (3), 187–195.

Punch, K. (2013) *Introduction to Social Research: Quantitative and Qualitative Approaches*. Sage Publications.

Punch, K. F. and Oancea, A. (2014) *Introduction to Research Methods in Education*. Thousand Oaks, CA: Sage Publications.

Qin, J., Lancaster, F. and Allen, B. (1997) Types and levels of collaboration in interdisciplinary research in the sciences. *Journal of the American Society for Information Science*, **48** (10), 893-916.

Rafols, I. and Meyer, M. (2010) Diversity and network coherence as indicators of interdisciplinarity: case studies in bionanoscience. *Scientometrics,* 82, 263 – 287.

Repko, A. F. (2008) *Interdisciplinary Research: Process and Theory*. Los Angeles: Sage.

Repko, A. F., Newell, W. H. and Szostak, R. (2012) *Case Studies in Interdisciplinary Research*. Thousand Oaks, CA: Sage.

Repko, A. F., Szostak, R. and Buchberger, M. (2017*) Introduction to Interdisciplinary Studies (2nd ed)*. Sage publications.

Rhoten, D. (2004) Interdisciplinary research: trend or transition? *Social Science Research Council: Items and Issues,* 5, (1-2), 6-11.

Rhoten, D. and Parker, A. (2004) Risks and Rewards of an Interdisciplinary Research Path. *Science*, 306 (5704), 2046.

Richards, L. (2005) *Handling qualitative data: a practical guide*. Sage publications.

Rimpiläinen, S. (2010) Knowledge in networks - knowing in transactions? EASST, September 2010, Trento, Italy, 1–12.

Rimpiläinen, S. (2012) Gathering, Translating, Enacting: A study of interdisciplinary research and development practices in Technology Enhanced Learning. PhD, University of Stirling.

Rimpiläinen, S. (2015) Multiple enactments of method, divergent hinterlands and production of multiple realities in educational research, *International Journal of Qualitative Studies in Education*. Routledge, **28** (2), 137–150.

Robson, C. (2011) *Real World Research*. London: Wiley.

Sá, C. (2007) Interdisciplinary strategies in US research universities. *Higher Education,* **55** (5), 537 – 552.

Saldaña, J. (2013) *The Coding Manual for Qualitative Researchers*. London: Sage.

Säljö, R. (2004) Learning and technologies, people and tools in co-ordinated activities. *International Journal of Educational Research*, **41** (6), 489-494.

Sayes, E. (2014) Actor-Network Theory and methodology: Just what does it mean to say that nonhumans have agency? *Social Studies of Science,* **44** (1), 134-149.

Scanlon, E. and Conole, G. (2018) Interdisciplinarity in Technology Enhanced Learning: An Interview Study. *Journal of Interactive Media in Education,* 2018(1): 12, 1–8.

Scanlon, E., Conole, G., Clough, G. and Blake, C. (2013) Interdisciplinary Knowledge Creation in Technology-Enhanced Learning. Lecture notes in computer science, 8095, 631–632.

Scardamalia, M. and Bereiter, C. (2006) Knowledge building: Theory, Pedagogy, and Technology. In: K. Sawyer (ed.) *Cambridge Handbook of the Learning Sciences*. New York: Cambridge University Press, 97-118.

Selwyn, N. (2010) Looking beyond learning: notes towards the critical study of educational technology. *Journal of Computer Assisted Learning*, **26** (1), 65–73.

Selwyn, N. (2013) *Education in a Digital World: Global Perspectives on Technology and Education*. London: Routledge.

Serres, M. (1974) *Hermès III, La Traduction*. Paris: Minuit.

Shapin, S. and Schaffer, S. (1985) *Leviathan and the Air-Pump: Hobbes, Boyle and the Experimental Life*. Princeton: Princeton University Press.

Shinn, T. (2005) New sources of radical innovation: Research technologies, transversality, and distributed learning in a post-industrial order. *Social Science Information*, **44** (4), 731–764.

Shrum, W., Genuth, J., and Chompalov, I. (2007) *The structures of scientific collaboration*. Cambridge, MA: MIT Press.

Siedlok, F. and Hibbert, P. (2014) The Organization of Interdisciplinary Research: Modes, drivers and barriers. *International Journal of Management Reviews,* **16** (2), 194-210.

Silverman, D. (2011). *Interpreting qualitative data: A guide to the principles of qualitative research*. London: SAGE.

Singleton, V. and Michael, M. (1993) Actor-networks and ambivalence: general practitioners in the UK cervical screening programme. *Social studies of science,* **23** (2), 227-264.

Sismondo, S. (2010) *An Introduction to Science and Technology Studies (2nd ed)*. Oxford: Wiley and Sons.

Slaughter, S., Campbell, T., Holleman, M. and Morgan, E. (2002) The "Traffic" in Graduate Students: Graduate Students as Tokens of Exchange between Academe and Industry. *Science, Technology & Human Values*, **27** (2), 282-312.

Smithson, J., Hennessy, C. and Means, R. (2012) Online Interaction and "Real Information Flow": Contrasts Between Talking About Interdisciplinarity and Achieving Interdisciplinary Collaboration. *Journal of Research Practice,* **8** (1), 1-19.

Sørensen, E. (2009) *The Materiality of Learning: Technology and Knowledge in Educational Practice*. Learning in Doing series, New York: Cambridge University Press.

Sovacool, B. K., Ryan, S., Stern, P., Janda, K., Rochlin, G., Spreng, D., Pasqualetti, M., Wilhite, H. and L. Lutzenhiser (2015) Integrating social science in energy research, *Energy Research & Social Science,* 6, 95–99.

Spelt, E., Biemans, H., Tobi, H., Luning, P. and Mulder, M. (2009) Teaching and learning in interdisciplinary higher education: a systematic review. *Educational Psychology Review*, 21, 365-378.

Spradley, J. (1980) *Participant observation*. New York: Holt, Rinehart and Winston.

Stahl, G. (2005) Group cognition in computer-assisted collaborative learning. *Journal of Computer Assisted Learning,* 21, 79-90.

Stahl, G., Koschmann, T. and Suthers, D. (2006) Computer-supported collaborative learning: An historical perspective. In: R. K. Sawyer (ed.) *Cambridge handbook of the learning sciences*. Cambridge, UK: Cambridge University Press, 409-426.

Stake, R. (1994) Case Studies. In: N. Denzin, and Y. Lincoln (eds.) *Handbook of qualitative research*. London: Sage, 236-247.

Stake, R. (2005) *The Art of Case Study Research*. Thousand Oaks, Sage.

Stake, R. (2008) Qualitative case studies. In: N. K. Denzin and Y. S. Lincoln (eds.), *Strategies of qualitative inquiry* (3rd ed). Thousand Oaks, CA: Sage, 119–150.

Stake, R. and Trumball, D. (1982) Naturalistic Generalizations. *Review Journal of Philosophy and Social Science,* 7 (1-2), 1-12.

Star, S. L. (1995) The politics of formal representations: Wizards, gurus and organisational complexity. In: S. L. Star (ed.) *Ecologies of Knowledge: Work, and politics in science and technology*. New York: State University of New York Press, 89 – 118.

Star, S. L. and Griesmer, J. R. (1989) Institutional Ecology, 'Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. *Social Studies of Science,* **19** (3), 387-420.

Strathern, M. (1996) Cutting the network. *Journal of the Royal Anthropological Institute*, 2, 517–535.

Strathern, M. (2004) *Commons and Borderlands: Working Papers on Interdisciplinarity, Accountability and the Flow of Knowledge*. Wantage: Sean Kingston.

Strathern, M. (2005) Laudable aims and problematic consequences, or: The 'flow' of knowledge is not neutral. *Economy and Society*, 33, 550-561.

Strathern, M. (2006) A community of critics? Thoughts on new knowledge. *Journal of the Royal Anthropological Institute,* **12** (1).

Strathern, M. and Khlinovskaya Rockhill, E. (2013) Unexpected Consequences and an Unanticipated Outcome. In: Barry, A. and Born, G. (eds.) *Interdisciplinarity: Reconfigurations of the Social and Natural Sciences*. London: Routledge, 119–140.

Strauss, A. and Corbin, J. (1990) *Basics of qualitative research grounded theory procedures and techniques*. Newbury Park, CA: Sage.

Strober, M. (2011) *Interdisciplinary conversations: Challenging habits of thought*. Stanford University Press.

Suchman, L. (1985) Plans and Situated Actions: The Problem of Human Machine Communication. *Contemporary Sociology*, **18** (3).

Suchman, L. (2006) *Human-Machine Reconfigurations: plans and situated actions*. Cambridge: Cambridge University Press.

Suchman, L. (2007) Anthropology as 'brand': reflections on corporate anthropology. Paper presented at the Colloquium on Interdisciplinarity and Society, Oxford University, 24 February.

Szerszynski, B. and Galarraga, M. (2013) Geoengineering knowledge: Interdisciplinarity and the shaping of climate engineering research. *Environment and Planning A,* **45** (12), 2817-2824.

Szostak, Rick (2017) About Interdisciplinarity. [Online]. Available from: https://sites.google.com/a/ualberta.ca/rick-szostak/research/about-interdisciplinarity [Accessed 8 August 2019]

Tait, J. and Lyall, C. (2001) Final report: short term investigation into ESRC funded interdisciplinary research. SUPRA, Final ESRC report.

Tatnall, A. and Gilding, A. (1999) Actor-Network Theory and Information Systems Research. Proceedings of the 10th Australasian Conference on Information Systems.

The British Academy (2016) Crossing Paths: Interdisciplinary institutions, careers, education and applications. Available from: https://www.thebritishacademy.ac.uk/sites/default/files/Crossing%20Paths%20-%20Full%20Report_2.pdf

Thompson, T. and Rimpiläinen, S. (2012) Unravelling knowledge practices: the assistances and resistances of ANT. The First Professional Practice, Education and Learning Conference (ProPEL), Stirling, Scotland.

Tily, R. (2016) Space, research objects, and interdisciplinarity in geomorphological inquiry (PhD thesis). University of Oxford.

Tobi, H. and Kampen, J. (2018) Research design: the methodology for interdisciplinary research framework. *Quality and Quantity*, **52** (3), 1209-1225.

Tracy, S. (2010) Qualitative Quality: Eight 'Big-Tent' Criteria for excellent qualitative research. *Qualitative Inquiry*, **16** (10), 837 – 851.

Trevino, L., Lengel, R., and Daft, R. (1987) Media symbolism, media richness, and media choice in organizations: a symbolic interactionist perspective. *Communication Research 14,* 553 – 574.

Trowler, P. R. (2014) Practice-focused ethnographies of higher education: method/ological corollaries of a social practice perspective. *European Journal of Higher Education*, **4** (1), 18-29.

Trowler, P., Saunders, M. and Bamber, V. (2012) *Tribes and Territories in the 21st Century: Rethinking the significance of disciplines in higher education.* Taylor & Francis Group.

Turner, B. (2006) Discipline. *Theory, Culture and Society*, **23** (2-3), 183-186.

Urry, J. (2000) *Sociology beyond societies: Mobilities for the twenty-first century*. London and New York: Routledge.

van Raan, A. F. J. and van Leeuwen, T. N. (2002) Assessment of the scientific basis of interdisciplinary, applied research: Application of bibliometric methods in Nutrition and Food Research. *Research Policy,* Elsevier, **31** (4), 611-632.

Vertesi, J. and Ribes, D. (2019) *digitalSTS: A field guide for Science and Technology Studies.* Princeton University Press.

vu Henry, J. (2018) Theorising the Design-Reality Gap in ICTD: Matters of Care in Mobile Learning for Kenyan Community Health Workers. PhD, UCL Institute of Education.

Vygotsky, L. S. (1978) *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wallsten, A. (2017) Assembling the Smart Grid: On the Mobilisation of Imaginaries, Users and Materialities in a Swedish Demonstration Project, PhD, Linköping University.

Webster, F. (2006) *Theories of the Information Society*. London: Routledge.

Weingart, P. and Stehr, N. (eds.) (2000) *Practising Interdisciplinarity*. University of Toronto Press: Toronto.

Welch, J. (2011) The Emergence of Interdisciplinarity from Epistemological Thought. *Issues in Integrative Studies*, 29, 1 – 39.

Welch, J. (2012) Interdisciplinarity and the Question of Being. *Issues in Integrative Studies,* **127** (30), 99-127.

Wenger, E. (1998) *Communities of Practice: learning, meaning and identity*. Cambridge, Cambridge University Press.

Wessels, B. and Craglia, M. (2007) Situated innovation of e-Social science: Integrating infrastructure, collaboration, and knowledge in developing e-Social science. *Journal of Computer-Mediated Communication*, **12** (2), 358–377.

Whatmore, S. (2003) Generating Materials. In: Pryke, M., Rose, G., Whatmore, S. (eds.) *Using Social Theory: Thinking Through Research.* London: Sage, 89-104.

Whatmore, S. (2013) Where Natural and Social Science Meet? Reflections on an experiment in geographical practice. In: Barry, A. and Born, G. (eds.) *Interdisciplinarity: reconfigurations of the social and natural sciences*. Abingdon: Routledge, 161-177.

White, P. (2013) Who's afraid of research questions? The neglect of research questions in the methods literature and a call for question-led methods teaching. *International Journal of Research and Method in Education*, **36** (3).

White, J., Drew, S. and Hay, T. (2009) Ethnography versus case study: positioning research and researchers. *Qualitative Research Journal*, **9** (1), 18-27.

Whitley R. (1984) *The Intellectual and Social Organization of the Sciences.* Oxford: Clarendon.

Whittle, A. and Spicer, A. (2008) Is actor network theory critique? *Organization Studies,* 29, 19.

Wilkie, A. (2010) User assemblages in design: An ethnographic study. PhD. Goldsmiths, University of London. Available from: http://eprints.gold.ac.uk/4710/ [Accessed 2 November 2017]

Williams, R. and Edge, D. (1996) The social shaping of technology. *Research Policy*, **25.** (6), 865–899.

Wong, C. M. L. (2016) Assembling Interdisciplinary Energy Research through an Actor Network Theory (ANT) frame. *Energy Research and Social Science*, 12, 106–110.

Woolgar, S. and Lezaun, J. (2013) The wrong bin bag: A turn to ontology in science and technology studies? *Social Studies of Science*, **43** (3), 321–340.

Woolgar, S. and Lezaun, J. (2015) Missing the (question) mark? What *is* a turn to ontology? *Social Studies of Science*, **45** (3), 462 –467.

Wright, S. (2016) Exploring Actor-Network Theory And CAQDAS: Provisional Principles and Practices for Coding, Connecting And Describing Data Using ATLAS.ti, *Qualitative Data Analysis and beyond. Proceedings of the ATLAS.ti User Conference*, 1–31.

Wuchty, S., Jones, B. and Uzzi, B. (2007) The increasing dominance of teams in production of knowledge. Science (New York), **316** (5827), 1036–9.

Yin, R. (1989) *Case study research: Design and methods.* Applied Social Research Series, 5. London: Sage.

Yin, R. (1994) *Case Study Research: Design and Methods*. London: Sage.

Zenzen, M. and Restivo, S. (1982) The mysterious morphology of immiscible liquids: A study of scientific practice. *Information (International Social Science Council),* **21** (3), 447-473.

APPENDICES

APPENDIX A: TERMINOLOGY

Actor: Any entity (human or non-human) within a network.

Actor-network: An actor-network can emerge with the 'successful alignment' of elements, but is in a 'constant churn of forming, staying together, or breaking apart' (Thompson and Rimpiläinen, 2012: 2). The relations that configure an actor-network are thought to constitute an 'arrangement of priorities' (Star, 1995: 89) - a snapshot of the social relations corresponding to the distribution of power at a given moment in time (Massey, 1991: 28).

Assemblage: 'A patterned array of connections and composed of all manner of heterogeneous elements' (Michael, 2017: 154).

Black box(ing): Some objects can be understood as 'black boxes' (Bijker, Hughes and Pinch, 1987: 8). Black boxes traditionally contain that which does not need to be considered, and a black box can be used in place of a piece of technology, for example, which is too complex to understand, and about which nothing is important apart from its input and output. A black box can be 'opened up' to see how it (should have) worked, and can be understood as another heterogeneous network of actors in-and-of-itself.

Device of interessement: An actor which 'interests' other actors in the problem or project at hand.

Digital Humanities: The Digital Humanities is a broad field of research and scholarly activity covering not only the use of digital, computing and scientific methods by humanities researchers, but also the ways in which the humanities offer distinctive insights into social and cultural issues raised by the development of digital technologies. 'The application of computation to the discipline of the humanities… is, and remains, a discipline very much under construction… [It] often requires a team of people with diverse backgrounds' (Berry and Fagerjord, 2017: 8).

Enactment: 'The ways in which discourses, practices, technologies, bodies act in ways to construct and distribute a particular reality' (Michael, 2017: 156 – 157). This can also be thought of as 'performance'.

Enrolment: The third of Callon's (1986) four 'moments' of translation. This is the 'successful' placing and acceptance of certain entities into designated roles, to coordinate 'appropriately' within a network.

Fluidity: As certain objects move across 'settings' and contexts, 'what they are can change as new associations enter into their making. This transitioning can be thought of in terms

of fluidity as the seemingly identical object changes over and over as it moves (much like a fluid)' (Michael, 2017: 157). For example, de Laet and Mol (2000) focus on the fluidity of a bush pump in Zimbabwe; while the bush pump is itself solid and mechanical, its boundaries are 'vague and moving'.

Generalised symmetry: Generalised symmetry attributes the potential for agency to non-humans as well as humans, emphasising the importance of applying common analytic tools. It stresses the role which non-humans or objects play in networks by ensuring not to privilege humans as the sole 'source of action'.

Heterogeneous engineering: Those actors who 'in building or engineering their networks have to marshal, enrol and arrange a multiplicity of humans, natures and technologies' (Michael, 2017: 158). ANT argues that certain practices are the result of a process of 'heterogeneous engineering' in which 'bits and pieces from the social, the technical, the conceptual, and the textual are fitted together' (Law, 1992: 380).

Heterogeneous networks: Heterogeneity signifies the ANT commitment to viewing the world as composed of a variety of elements, including technologies and humans, for example. Networks consist of heterogeneous participants, evident from the intertwinement of human and non-human actors and objects. "The idea of heterogeneity refers to the 'bits and pieces', which might include people, technologies, materials, processes, and so on" (Oliver, 2011: 379).

'Hinterland': Used by Rimpiläinen (2015) in her study of interdisciplinary research methods, borrowing from Law (2004), a 'hinterland' represents background, expertise, approach, and experience. As such, a 'disciplinary hinterland' references an individuals' (or indeed, an objects') network of disciplinary affiliations, their disciplinary 'background', education, training, and so on.

Immutable mobile: An immutable mobile is something that moves around but also 'holds its shape'. Immutability is 'allied to mobility… [where objects] retain their meaning as they move' (Michael, 2017: 159). 'Immutable mobiles have the capacity to fix knowledge and allow it to be disseminated far beyond its point of origin', explain Hassard and Alcadipani (2010: 9).

Inscription: An inscription can be the result of a translation of interests into material form (Callon, 1991: 143), and the notion of inscription refers to the way technical artefacts embody patterns of use. Knowledge can be 'embedded' in procedures of inscription (Latour, 1987).

Interessement: The second of Callon's (1986) four 'moments' of translation. These are practices that an actor employs to 'interest' other actors towards a certain plan or project, beginning to impose particular roles, identities and interests on them, as their 'terms of involvement… are negotiated and established' (Nimmo, 2016: xxxii).

Mobilisation: The fourth of Callon's (1986) four 'moments' of translation. This is when a spokesperson can represent a network externally, 'when the network becomes sufficiently durable that its translations are extended to other locations and domains' (Fenwick and Edwards, 2010: 14).

Obligatory Passage Point (OPP): Developed by Callon (1986), an OPP is usually part of 'problematisation', and can be thought of as a 'funnel' which through which actors converge on a certain purpose or question. 'To enrol actors is also to orient them towards particular sites… To realise their new role (or identity) these enrolees must necessarily pass through such obligatory passage points' (Michael, 2017: 161). This is where the decision is made as to 'what counts' as 'legitimate' knowledge.

Ontological multiplicity: This concept draws on the argument that reality, or ontology, is enacted. For example, for Mol (1999, 2002), practices enact realities, and therefore different practices, or 'enactments', generate different realities, or 'ontologies'. Different enactments generate a multiplicity of realities, and this suggests there is no 'real' reality behind these enactments. This is a move from an 'epistemological approach, that sees mess as a result of different perspectives on a singular object, [towards] the ontological approach, which sees mess as a result of the multiplicity of objects' (Donaldson, Ward and Bradley, 2010: 1531). This ontological multiplicity lies at the heart of what Mol terms 'ontological politics'.

Ontological politics: This directs attention towards the way certain socio-material arrangements perform their own realities. Ontologies can relate to each other in different ways, sometimes overlapping, sometimes conflicting or sometimes co-existing. "This is also a theory of multiplicity, since it involves the contention that realities – as enactments embedded in particular practices – are always local and multiple; hence realities co-exist and overlap, and can also be in tension with one another… [which] becomes a political matter, a matter of 'ontological politics'" (Nimmo, 2016: xxxvi).

Praxiography: A 'praxiographic' approach employs the methods of ethnography to address the materiality of practice, focussing 'the ethnographer's lens… at the level of practice' (vu Henry, 2018: 69 – 70). It is 'a particular take on ethnography which sees the world in a specific way… A praxiographic approach… privileges close up, in-depth, case study-based research designs of the ethnographic sort' (Trowler, 2014: 18 - 20).

Problematisation: The first of Callon's (1986) four 'moments' of translation. It is the definition of a 'problem' at the start of the process of translation.

Socio-materiality: Socio-materiality advances the view that organisations, work, discourses, people and technology (e.g. the social and the 'material'), for example, should be conceptualised as being inherently entangled and thus inseparable, rather than the 'taken-for-granted assumption' that they are separate entities. It is used in Actor-Network Theory (ANT), among other theoretical and conceptual framings.

Token: A human or non-human focal actor whose path can be followed to find a 'way through' a complex actor-network.

Translation: Translation focusses on what happens at each of the connections between heterogeneous participants in a network, tracing how things 'come to be', or do not. 'To translate is to redefine another's interests or identity… Through translation, actors become enrolled into an actor-network' (Michael, 2017: 164). Lezaun (2017: 4) describes translation as 'an act of invention that operates by joining previously disparate elements. 2010). Baiocchi, Graizbord and Rodríguez-Muñiz (2013: 330) add that '…as with other ANT concepts (and the meaning of ANT itself), its definition is slippery and has received different accents by different authors and at different moments in ANT's life course. At its most basic, translation refers to techniques or practices that establish connections'. "Actors have their interests translated… and their relations reconfigured, and as such they are locally 're-made' as individuals" explains Michael (2017: 22).

APPENDIX B: PILOT STUDY (MSc) CASES

Project	Participant 1	Participant 2	Participant 3	Participant 4	Technologies
The Ashmolean Latin Inscriptions Project	Classical Archaeologist *(ex-teacher)*	Technologist *(background in Classics)*	Ancient Historian	Ancient Historian	Reflectance Transformation Imaging (RTI) hardware and software; EpiDoc
Poetry Visualisations	Linguist	Computer Scientist	Poet		Poem Viewer; Semantic Tagger
The Oxford e-Social Science Research Project	Sociologist	Information Scientist	Historian	Computer Scientist	-
The Future of Humanity Institute with Amlin	Ecologist	Computational neuroscientist	Computer Scientist		Modelling software

APPENDIX C: CASE SCOPING INTERVIEWS

UNIVERSITY A				
Participant code	**Main research area**	**Other disciplinary affiliations**	**Project/Research group**	**Further contact?**
P1	'Learning Innovation'	Computer science	Education technology	
P2	Holographic television	Visual studies	Digital media	X
P3	Engineering	Materials science	Digital media	
P4	Furniture design	Biology	'Mediated technology'	
P5	Engineering	'Entrepreneurship'	Education	
P6	Music composition	-	Digital instruments	X
FG (5 participants)	Digital media	-	Comparative media	

UNIVERSITY X*				
Participant code	**Main research area**	**Other disciplinary affiliations**	**Project/Research group**	**Further contact?**
P7	Maths	Linguistics	'Human sciences and technology'	X
P8	Biology	Engineering	Bio-technology	X
P9* ('the Hub')	Education	-	Industry-academia relations	X
P10 and P11*	Renaissance history/technology	French literature	Social networks in history	X
P12	Digital Humanities	-	Digital Humanities	
P13	'Triple Helix'	Education	-	X

P14*	Education	Human behaviour	Energy	X
OBS1	Energy	-	Environment	X
OBS2	Engineering	-	Energy	

UNIVERSITY B			
Participant code	**Main research area**	**Other disciplinary affiliations**	**Further contact?**
P15	Bio-technology	Entrepreneurship	X
P16	Art History	Digital Art	

APPENDIX D: University X invitation and endorsement letters

[redacted]

March 16, 2017

To Whom it may concern.

I am writing to unequivocally endorse Erin Young for a period of study at [redacted] as a visiting researcher of the Human Sciences and Technology Advanced Research Institute, the parent organization of [redacted]

[redacted]'s history and current practice of interdisciplinary research make it an idea environment for Erin's data collection for her dissertation study. During the year that Erin Young intends to be at [redacted] following [redacted] activities are planned. By virtue of her participant-observer research method, she will take an active roll in these.

- Observation and participation in catalyst interface activities involving [redacted] faculty and researchers, local community affiliates, and international industry members.
- Interviews with [redacted] affiliated faculty, laboratories and corporate stakeholders.
- Analysis and curation of research results from prior interdisciplinary research themes.
- Planning and implementation of three interdisciplinary research themes, each with project management and reporting activities for academic and industry collaborators, with written summaries at popular and scientific levels.
- Planning and implementation of 3 to 4 industry-university conferences with interdisciplinary workshop activities.

During the period of her position as an official "Visiting Researcher" at [redacted], Erin will have [redacted] SUNet ID, which provides access to [redacted] libraries, other [redacted] facilities, and desk space in Ventura Hall, the main office of [redacted]

On behalf of the [redacted] University, we look forward to Erin's participation and period of study, and to further developing collaborations between [redacted] and Oxford.

Cordially,

[redacted]

[redacted]

[redacted]

Ms. Erin Lorelie Young
Brasenose College
University of Oxford
Oxford OX1 3PA, UK

Dear Erin,

It is our pleasure to extend an invitation for you to join [redacted] as a visiting student researcher with Professor [redacted]'s research group with the Graduate School of Education for a period of 12 months beginning May 1, 2017 and ending April 30, 2018. Please note that this invitation is contingent on approval by Graduate Admissions, Office of the University Registrar not to exceed twelve months and J-1 visa approval.

I have attached a brief description of your responsibilities during your appointment at [redacted]. If you have any questions about the work that we expect you will be doing here, please contact Professor [redacted]

As a Visiting Student Researcher, you must pay the monthly VSR fees for each full or partial month in which you are in residence at [redacted]. The VSR fee for the 2016-2017 academic year is $1026 per month. This fee cannot be prorated, so you will be responsible for the full amount for each month. To ensure that you are protected by health insurance, you will automatically be enrolled and billed for [redacted]s health insurance (Cardinal Care) each quarter you are here. The Cardinal Care fee is $ 4968 per year for the 2016-2017 academic year, charged in three payments of $1656 (charged at the beginning of Autumn, Winter and Spring quarters.) If you have alternative health coverage, you may wish to waive Cardinal Care. Please note that if you wish to waive Cardinal Care, you must waive out in Axess by the quarterly deadline of 9/15; 12/15; **3/15**; or 6/15 based on your entry quarter. If you are an international VSR, you will need to submit the International Student Insurance Coverage Certification form to the Vaden Student Health Center: [redacted]ents . Information [redacted]ealth Services Fee of $ 203 per quarter. This fee cannot be waived or pro-rated. [redacted] University does not accept credit cards for payment of student accounts.

You will receive a student photo ID card that permits entry to and borrowing privileges from the [redacted] libraries, use of recreational facilities, use of Vaden Student Health services, and email and other computing services.

[redacted] will provide you with:

1. a desk in a shared office in Ventura Hall
2. network access (Ethernet and/or wireless LAN)

We expect all visitors to bring their own laptop computer; we do not provide visitors with computers.

[redacted]

APPENDIX E: Interview participants

Case Study 1: Medical Robotics

Participant[134]	Self-titled disciplinary/interdisciplinary role/background/area	Date interviewed
Jennifer	Post-doc Biomedical Engineer	17th May 2017
Jennifer	"	14th July 2017
Jennifer	"	7th March 2018
Pete	Interventional Radiologist	9th November 2017
Pete	"	23rd March 2018
Selena	Lab technician/biomedical engineer	4th December 2017
Joseph	Graduate Student in Mechanical Engineering/Software Engineer	28th February 2018
Mina	Interventional Radiologist	10th April 2018
Sophie	PhD Student in Mechanical Engineering	13th March 2018
Haruto	Industry lab technician	22nd March 2018
Rohit	Industry lab technician	22nd March 2018

Case Study 2: Digital Humanities

Participant	Self-titled disciplinary/interdisciplinary background/area	Date interviewed
David	Professor of French and History	12th October 2017
Nicola	Digital Research Architect in the Humanities	30th October 2017
Nicola	"	14th May 2017
Jim	Designer-developer and Visual Communications student	3rd December 2017
Todd	Designer-developer and Visual Communications student	3rd December 2017
Ewan	Software engineer and IT consultant	2nd December 2017
Ren	Computer Science professor	2nd December 2017

[134] Pseudonyms are used for participant anonymity.

Case Study 3: Energy

Participant	Self-titled disciplinary/interdisciplinary background/area	Date interviewed
Janet	Senior Research Scientist/administrator in the Social Sciences	14th May 2017
Janet	"	14th December 2017
Raj	Associate Professor in Civil and Environmental Engineering	4th December 2017
Marco	PhD candidate in Civil and Environmental Engineering/postgraduate researcher	1st September 2017
Marco	"	23rd May 2018
Jack	Software Architect	1st September 2017
Jack	"	23rd May 2018
Grant	MBA/MS student at University X Business School	9th October 2017
Michael	PhD student in Civil and Environmental Engineering	30th October 2017
Wujing	Postdoctoral scholar in data analytics and civil engineering	9th November 2017
Timothy	PhD student in Electrical Engineering	14th November 2017
Gino	Staff scientist at the National Lab/Electrical Engineer	12th December 2017
Daniel	Staff scientist at National Lab/Mechanical Engineer	23rd April 2018
Lauren	Project financial manager/administrator	23rd April 2018
Lilian	Master's student in Mechanical Engineering	28th February 2018
Aman	Chair of the Department and Professor of Electrical Engineering at University X	2nd April 2018
Priya	Software and mobile developer/Android app designer	7th March 2018

APPENDIX F: SAMPLE SEMI-STRUCTURED INTERVIEW SCHEDULE (CS3)

Section	Question	Follow-up questions
Introduction to case	1. The project seems to be split into different sub-groups working on different elements of the project? Is this correct? If so, could you please tell me about the part on which you work, please? *Am I correct in thinking that there are different components/teams which will eventually come together?* Are different technologies developed by different groups? *Do they focus on different technological aspects?*	• What stage is your work on the project at? *(Milestones?)* • What knowledge does the project aim to build? • In one team meeting you said that it would be 'interesting for different parts of the project to interact'. What did you mean?
	2. Am I correct that you have quite a central role in the organisation of the project? In the previous team meeting it seems that X relies on you a lot, specifically to set up the lab, and to co-ordinate a sub-team in doing this.	• How did you come into the project? • Are you associated with both [institutions]? • Did you have input on the research questions? • With whom do you work most closely? Am I right in thinking that you work closely with X on X?
	3. What is the most important aim of the project for you?	• What new technologies are being built?
Researcher background	4. Within which disciplinary or interdisciplinary area would you class that you primarily work?	• Have been you involved in other interdisciplinary projects previously? • What is your disciplinary (or interdisciplinary) background?
Interdisciplinarity in the case	5. In what ways is this project interdisciplinary, if at all?	• How do you define interdisciplinarity? What do you think it is? • Is it happening as you thought it would when you first joined the project? • Do you see yourself as an interdisciplinary researcher, or simply working on an interdisciplinary project, or neither?
	6. What project methodology or methodological practices are you currently using on the project? I notice a lot of focus around the milestones and what will be presented to the funders in the team meetings. Do you ever	• How does this compare to the methodological approaches you use in your other (disciplinary) work? • What kinds of theoretical or methodological choices have you had to make so far in this project, if any? • Have you negotiated any of your personal theoretical or methodological viewpoints?

	find this dictates, affects or changes methodologies and ways of working for you?	
	7. Can you describe your weekly interactions with colleagues from other disciplines on the project?	• Have you ever encountered any difficulties? • Who makes the decisions? • *How does X team, work with Y team, work with Z team?*
	8. How do you find working in an interdisciplinary way? / How do you find working with the other disciplines in co-creating new technology?	• Do you ever find working with others, or working with this technology, changes your practices, opinions or methodologies? • Or in your opinion, have you have affected others? • Have you taught or learned anything about other disciplinary ways of working, practices or thinking on the project so far?
	9. Have there been any moments when you have felt that the interdisciplinarity has 'worked' particularly well? Or not so well?	• What have been the most interesting 'moments' on the project for you so far?
Technology-in-development	10. I'd like to explore further the technologies which the project is developing. Could you tell me about the new technologies which you are building? What is the process of technology development?	• What stage of technology development is the project currently at? • How do you see that this technology might be of benefit? • What do you think is the relationship between this technology and the new knowledge which you are co-creating on the project, if any? Are they the same?
	11. Could you talk more about your involvement in the technology development, please?	• What is your input/role in the design and creation of the technology? • Has working with this technology affected your practices?
	12. What other outputs are planned, or have emerged so far, besides the technology?	*This could include articles, conference papers, patents, etc. Is knowledge produced in the form of technologies, papers or patents in the project?*
	13. Which existing technologies do you use for collaboration and research purposes on the project?	• And in your own disciplinary work? *(Eg. emails, online forum, Slack, MRI machine?)*
Final Thoughts	14. Is there any way you wish the project were different? Or can think of any other disciplinary input which might be of benefit?	Do you think of the 'tech to market' (business) aspect as a different disciplinary input or not?
	15. Do you have any final thoughts or comments you would like to raise?	

Pre-interview

1. Thank you for agreeing to be interviewed.
2. Having read the Participant Information Sheet, would you like me to explain my research again briefly?
3. I am recording the interview for transcription purposes only. The recording will be erased when I have finished with it.
4. Please tell me if you would like to say something off the record.
5. Do you have any further questions?
6. Please sign the consent form.

Post-interview

1. Thank you!
2. Would you mind sharing any documents which you have created or have access to within the project please? This can be anything from articles, conference papers, presentation slides, photographs, photographs, emails, grant proposals, etc.
3. Would you mind showing me the technology you are building, please?
4. Would you mind showing me around any of your workspaces please?
5. With who else would you recommend for me to speak?

APPENDIX G: CUREC and IRB approval letters

Gmail

Erin Young <erinlorelieyoung@gmail.com>

CUREC APPROVAL

5 messages

Heath Rose <heath.rose@education.ox.ac.uk> 25 April 2017 at 08:08
To: "erin.young@education.ox.ac.uk" <erin.young@education.ox.ac.uk>
Cc: Niall Winters <niall.winters@education.ox.ac.uk>, Rebecca Eynon <rebecca.eynon@oii.ox.ac.uk>

Application Approval

Title: Synaptic Scholarship: An investigation into the mediation of emerging technology in interdisciplinarity within Higher Education

Researchers:
Erin Young and Niall Winters/Rebecca Eynon (Supervisors)

The above application has been considered on behalf of the Departmental Research Ethics Committee (DREC) in accordance with the procedures laid down by the University for ethical approval of all research involving human participants.

I am pleased to inform you that, on the basis of the information provided to DREC, the proposed research has been judged as meeting appropriate ethical standards, and accordingly, approval has been granted.

Please note that CUREC approval does not guarantee access to participants, and it is your responsibility to check whether countries or contexts in which you plan to conduct your research might impose additional requirements.

If your research involves participants whose ability to give free and informed consent is in question (this includes those under 18 and vulnerable adults), then it is advisable to read the following NSPCC professional reporting requirements for cases of suspected abuse
http://www.nspcc.org.uk/globalassets/documents/information-service/factsheet-child-abuse-reporting-requirements-professionals.pdf

Should there be any subsequent changes to the project which raise ethical issues not covered in the original application you should submit details to research.office@education.ox.ac.uk for consideration.

Good luck with your research study.

Yours sincerely,
Heath Rose
--
Heath Rose
Associate Professor of Applied Linguistics
Department of Education
University of Oxford
15 Norham Gardens
Oxford, OX2 6PY
United Kingdom
TEL: +44-1865-274033

Gmail

Erin Young <erinlorelieyoung@gmail.com>

IRB Protocol Approved: 41920, Young, (NEW) **WE WANT YOUR FEEDBACK - SEE SURVEY LINK**

2 messages

irb2-manag
To: erinly@
Cc: martha.

****
As part of ongoing IRB quality improvement, please complete this short IRB Post-Approval Survey:
http://www.surveymonkey.com/s/IRBsurvey-2
It is anonymous and takes about 5 minutes. Your input is important - thank you for your time.
****

This email is to notify you that the protocol listed below has been approved by the IRB.

Protocol: 41920 (NEW)
Review Type: EXPEDITED
Protocol Director: Erin Lorelie Young
Department: Graduate School of Education
Protocol Title: An investigation into the mediation of emerging technology in interdisciplinarity within Higher Education



APPENDIX H: Research consent forms (CUREC and IRB)

[redacted] UNIVERSITY Research Consent Form

Protocol Director: Ms. Erin Young

Protocol Title: An investigation into the mediation of emerging technology in interdisciplinarity within Higher Education

DESCRIPTION: You are invited to participate in a research study on how interdisciplinary research happens in Higher Education, and how new technologies can emerge from it. I am a graduate student at Oxford University, and a Visiting Researcher at [redacted]ersity, and this study will contribute to my DPhil (PhD) research. The project is an ethnographic (the study of people and their culture), collective case study (a research strategy which focuses on a group in a certain context within one time period) which explores three University-based interdisciplinary research projects. I would like to follow the processes of these teams moving from research questions to technological outcomes in order to investigate how new technologies and new knowledge are co-created through interdisciplinary practices. You have been invited to participate because you are a researcher working within one of the interdisciplinary projects identified as a case study, or within the wider interdisciplinary ecosystem. This research ultimately aims to inform future technological and social practices, and enhance theoretical understandings within interdisciplinarity.

If you are happy to take part, you will be included in the case study of your research project, along with the other researchers who have given their consent. The study will take place at your University in the next few months, in physical and virtual spaces. In order to study the selected cases, this research will integrate findings from interviews, observations and documentary analysis. Therefore, you will be invited for 1-3 short audio-recorded interviews with myself, across the course of a year, whenever is most convenient for you. Your level of participation is entirely at your discretion, and all audio recordings will be used for transcription purposes only. Recordings will be erased once transcription has taken place, and transcripts will remain anonymous. Full transcripts will remain confidential, although anonymous quotations may be used. The audio recorder can also be switched off at any time. Interviews will focus on your views of interdisciplinarity; reflections on your research project including methodologies and technologies; your disciplinary background; among other things, as well as anything else which you may wish to discuss. You may also be asked to share any project documents which you might find relevant, such as articles, grant proposals, presentations and websites, as well as to talk about and explain the technologies which you are building. Photographs of technologies in development might also be taken with your consent. You can share as much or as little information as you wish. I will also conduct observations during team meetings or project discussions. There will not be any follow-up visits, and you can ask questions at any time.

TIME INVOLVEMENT: Your participation will take approximately a minimum of 45 minutes to a maximum of two weeks, across a few months to a year. Amount of participation is entirely at your discretion.

RISKS AND BENEFITS: The risks associated with this study are minimal, and as the researcher I will mitigate any potential risk by adhering to professional guidelines including the Statement of Ethical Practice from The British Sociological Association. Transparency will be maintained throughout. Your identity will never be disclosed and confidentiality of your individual identity and data will be maintained, although please be aware that any written materials and documents provided with regards to your research project, such as published conference or journal articles, may be referenced and cited in the final DPhil thesis, and other written materials resulting from the study. Your

employment will not be affected in any way, and you are not at risk of any coercion or undue influence. No information will be communicated between cases or participants, unless it is explicitly stated that this allowed.

All audio recordings will be erased following immediate transcription. Transcription will use codes instead of names to protect your and your colleagues' confidentiality and anonymity, and although your project may be named or described, I will ensure that no sensitive data or information is shared outside of project boundaries or within my final thesis. All data provided will be stored and managed electronically and securely within an encrypted device, and only myself and my two DPhil (PhD) project supervisors, based at Oxford University, will have access to the data.

I cannot and do not guarantee or promise that you will receive any benefits from this study. However, I believe that you have something very valuable to contribute, and I hope that you might find it enjoyable, and even illuminating, as a researcher to contribute to this research.

PAYMENTS: You will receive no payment for your participation.

PARTICIPANT'S RIGHTS: If you have read this form and have decided to participate in this project, please understand your participation is voluntary and you have the right to withdraw your consent or discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled. The alternative is not to participate. You have the right to refuse to answer particular questions. The results of this research study may be presented at scientific or professional meetings or published in academic journals.

CONTACT INFORMATION:

Questions: If you have any questions, concerns or complaints about this research, its procedures, risks and benefits, contact the Protocol Director, Ms. Erin Young (650-334-6219) at erinly[redacted]u or erin.young@education.ox.ac.uk. You may also contact my DPhil (PhD) supervisors, Dr. Niall Winters, niall.winters@education.ox.ac.uk (+441865274007), and Prof. Rebecca Eynon, Rebecca.eynon@oii.ox.ac.uk (+441865287206).

Independent Contact: If you are not satisfied with how this study is being conducted, or if you have any concerns, complaints, or general questions about the

[redacted]

Indicate ***Yes*** or ***No***:

I give consent to be audiotaped during this study.

___Yes___No

[redacted] **UNIVERSITY Research Consent Form**

Protocol Director: Ms. Erin Young

Protocol Title: An investigation into the mediation of emerging technology in interdisciplinarity within Higher Education

I give consent for the researcher to use the tapes for transcription.

✓ Yes ___ No

I give consent for the researcher to use short quotations from my transcripts for the DPhil thesis, as well as any scientific reports, conference presentations or other written materials based on this work (any excerpts used will remain anonymous).

✓ Yes ___ No

I give consent for any written materials I provide to the researcher to be cited in the DPhil thesis, unless I request otherwise.

✓ Yes ___ No

The extra copy of this signed and dated consent form is for you to keep.

SIGNATURE [redacted] **DATE** 5/12/2013

Print name of participant _____

Department of Education
15 Norham Gardens
Oxford
OX2 6PY



Ms. Erin Young, DPhil candidate
erin.young@education.ox.ac.uk
erinly@stanford.edu
+44(0)7847093839

An investigation into the mediation of emerging technology in interdisciplinarity within Higher Education

PARTICIPANT INFORMATION SHEET

1. ***Background and aims of the study***

Increasing prominence has been given to interdisciplinary collaboration as a means of addressing the most pressing challenges of the 21st century, and new technologies have been positioned as mediating artefacts in these endeavours. Yet it has been made clear that there is a need for an enhanced theoretical understanding of technologically-mediated interdisciplinary practices in order to acknowledge the complexities of the phenomena. Drawing conceptually from Science and Technology Studies (STS), this research will focus on generating new insights into deeper aspects of how interdisciplinarity happens in Higher Education, and how new technologies can emerge from it. This study hopes to answer the following questions: What is the relationship between emerging technologies and knowledge co-production in interdisciplinary research? How are methodologies re-negotiated in interdisciplinary research? How are new technologies created during interdisciplinary research practices? These questions will be tackled through an ethnographically-informed, collective case study which explores three University-based interdisciplinary research projects. I hope that my future work can be re-used in assessing practices, contributing to novel methodological developments regarding technology-mediated interdisciplinary practice. This study is funded by the Economic and Social Research Council, and the Engineering and Physical Sciences Research Council.

2. ***Why have I been invited to take part?***

You have been invited because you are a researcher working within one of the interdisciplinary projects identified as a case study, within which new and innovative technology is being developed.

3. ***Do I have to take part?***

No. You can ask questions about the study before deciding whether or not to participate. If you do agree to participate, your participation is voluntary and you may withdraw from the study at any time, without giving a reason and without penalty, by advising the researcher of this decision. You also have the right to refuse to answer particular questions. However, I believe that you have something very important to contribute, and I hope that you will take part.

4. ***What will happen in the study?***

If you are happy to take part, you will be included within the case study of your research project, alongside the other researchers on the project who have given their consent. The study will take place at your University during the next few months, in physical and virtual spaces. In order to study the selected cases, this research will integrate findings from interviews, observations, documentary analysis, network mapping, and technical artefact analysis. You may therefore be invited for 1-3 interviews with myself, lasting 30 minutes-1 hour each, across the course of a year, **but level of participation is entirely at your discretion**. If

you agree to be interviewed, you will be asked to sign a consent form and all interview data will be confidential. The interviews will be audio-recorded with your consent, for transcription purposes only, and we can hold them whenever and wherever is most convenient for you. Interviews will focus on your views of interdisciplinarity; reflections on your research project including project methodologies; research technologies being built; your disciplinary background; among other areas, and anything else about which you might wish to speak. You might also be asked to share any project documents which you might find relevant, such as articles, grant proposals, websites, conference papers, presentations, and so on, as well as to talk about and explain the technologies which you are building. **You can share as much or as little as you wish**. Photographs of technologies in development might also be taken with your consent. The researcher, myself, will also conduct observations during team meetings or project discussions. Data collected will then be analysed through network mapping, qualitative coding and analysis. There will not be any follow-up visits, and you can ask questions at any time.

5. ***Are there any potential risks in taking part?***

   There is little risk in taking part, but as the researcher I will mitigate any potential risk by adhering to professional guidelines as outlined by The British Educational Research Association (Ethical Guidelines for Educational Practice), The British Sociological Association (Statement of Ethical Practice) and the Economic and Social Research Council (Framework for Research Ethics), keeping your data confidential and giving you the right to withdraw or refuse participation. Your identity will never be disclosed and confidentiality of your individual identity and data will be maintained, although please be aware that any written materials and documents provided with regards to your research project, such as published conference or journal articles, may be referenced and cited in the final DPhil thesis, and other written materials resulting from the study. No information will be communicated between cases or participants, unless it is explicitly stated that this allowed. Transparency will be maintained throughout and research will only take place with fully-informed consent.

6. ***Are there any benefits in taking part?***

   I hope that the experience of taking part in this study will be enjoyable for you, and perhaps even illuminating! As a researcher yourself, I hope that you would find it rewarding to be able to contribute to a piece of research that ultimately aims to inform future technological and social practices within interdisciplinary collaboration. Given that researchers are often the sources of emerging technologies, this study could accelerate the process of translating research into new technologies. There is also the potential to inform industry partners, funding agencies, governments and university leaders with regards to which technological provisions should be made to facilitate effective interdisciplinary practice.

7. ***What happens to the data provided?***

   The research data will be stored electronically, securely and confidentially according to the University of Oxford Information Security Policy, in a secure file encoded with a password. All data provided will be managed within an encrypted device. Interview data will be transcribed digitally, and you and your colleagues' confidentiality will be preserved through the use of codes instead of names in transcriptions. Audio recordings will be erased once transcription has taken place, and transcripts will remain confidential. All your responses will be anonymised, unless you request otherwise, and direct quotations may be used. Observation, documentary and technical artefact notes will be transferred daily into digital formats, and any original handwritten versions will be destroyed. Photographs of technological project outputs and other relevant artefacts may also be obtained and stored in this way with consent. Only myself, the researcher, and my two DPhil supervisors will have access to the raw data. Although your project may be named or described, I will ensure that no sensitive data or information is shared outside of project boundaries or within my final thesis. All research data and records will be stored for a minimum retention

period of 3 years after publication of the work of the research.

8. ***Will the research be published?***
The University of Oxford is committed to the dissemination of its research for the benefit of society and the economy and, in support of this commitment, has established an online archive of research materials. This archive includes digital copies of student theses successfully submitted as part of a University of Oxford postgraduate degree programme. Holding the archive online gives easy access for researchers to the full text of freely available theses, thereby increasing the likely impact and use of that research. If you agree to participate in this study, the research will be written up as a thesis. On successful submission of the thesis, it will be deposited both in print and online in the University archives, to facilitate its use in future research. The thesis will be published open access.

9. ***Who has reviewed this study?***
This study has been reviewed by, and received ethics clearance through, the University of Oxford Central University Research Ethics Committee (CUREC), and the [redacted]University Research Compliance Office Institutional Review Board (IRB). It has also been thoroughly reviewed by the researcher's supervisors, Prof. Rebecca Eynon and Dr. Niall Winters.

10. ***Who do I contact if I have a concern about the study or I wish to complain?***
If you have a concern about any aspect of this study, please speak to the relevant researcher or their supervisor who will do their best to answer your query:

Name: Ms. Erin Young
Status: DPhil candidate, Education
Email: erin.young@education.ox.ac.uk
[redacted]
Tel: +44(0)7847093839

Supervisor: Dr. Niall Winters
Email: niall.winters@education.ox.ac.uk
Tel: +44 (0)1865 274007

Supervisor: Prof. Rebecca Eynon
Email: rebecca.eynon@oii.ox.ac.uk
Tel: +44 (0)1865 287206
[redacted]d Graduate School of Education

The researcher should acknowledge your concern within 10 working days and give you an indication of how they intend to deal with it. If you remain unhappy or wish to make a formal complaint, please contact the Chair of the **Social Sciences and Humanities Inter-Divisional Research Ethics Committee** at the University of Oxford who will seek to resolve the matter in a reasonably expeditious manner:

Email: ethics@socsci.ox.ac.uk
Address: Research Services, University of Oxford, Wellington Square, Oxford OX1 2JD

11. ***Further Information and Contact Details***

If you would like to discuss the research with someone beforehand (or if you have questions afterwards), please contact:

Ms. Erin Young
Department of Education
15 Norham Gardens, Oxford, OX2 6PY
Tel: +44(0)7847093839
Email: erin.young@education.ox.ac.uk



CITI PROGRAM

Expiration Date 01-Jun-2020
Record ID 23315563

This is to certify that:

erin lorelie young

Has completed the following CITI Program course:

Human Subjects Research Protections (Curriculum Group)
Group 2: IRB Nonmedical Research (All Nonmedical Investigators and Staff) (Course Learner Group)
1 - Basic Course (Stage)

Under requirements set by:

[redacted] **University**

Verify at www.citiprogram.org/verify/?w96cae598-c460-4a41-91af-c2b92da46e20-23315563