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Interdisciplinarity as a political instrument of governance and its consequences for doctoral training

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PhD in Science and Technology Studies

The University of Edinburgh

2022
Declaration

I, Nathalie Dupin, declare that this thesis has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree.

Except where stated otherwise by reference or acknowledgement, the work presented is entirely my own.

Signature:

Date:
Abstract

UK educational policies exploit interdisciplinarity as a marketing tool in a competitive educational world by building images of prosperous futures for society, the economy, and universities. Following this narrative, interdisciplinary science is promoted as superior to disciplinary forms of research and requires the training of future researchers accordingly, with interdisciplinary doctoral education becoming more established in universities.

This emphasis on the growth of interdisciplinary science polarises scholars’ views on the role of academic research between the production of knowledge on the one hand and knowledge as an economic resource at the other end of the spectrum. This research asks: what is the rationale behind the perceived value of interdisciplinary research and training, and how does it affect graduate students’ experiences of their PhD?

Based on a practice theory perspective for its suitability in generating insights into how university’s social life is organised, reproduced and transformed, the doctorate is conceptualised as sets of interconnected practices that are observable as they happen. This current study, therefore, comprised two stages of data collection and analysis; the examination of documents to elucidate educational policy practices and an educational ethnography of an interdisciplinary doctoral programme.

This study found interdisciplinary doctoral training is hindered by the lack of role models and positive social relationships, which are crucial to the way
interdisciplinary students learn. Furthermore, it is argued that interdisciplinarity is sometimes applied to research as a label to fit with funders' requirements. Specifically, in this case, medical optical imaging is best seen as an interdiscipline as it does not exhibit true interdisciplinary integration.

Further insights show that while interdisciplinarity is promoted in policy around promises and expectations for a better future, it is in tension with how it is organisationally embedded in higher education. These insights form the basis for a list of practical recommendations for institutions. Overall, interdisciplinary doctoral training was observed to present students with difficulties and to leave policy concerns unaddressed.
Lay Summary

Interdisciplinary science draws on two or more branches of knowledge instead of a single discipline, which is the norm traditionally valued in universities. Interdisciplinarity is promoted in UK higher education as potentially superior knowledge for addressing societies’ most problematic issues, which are thought to require that scientists work collaboratively. Given this insistence on interdisciplinarity, university degrees have been developed to train students with the abilities and skills to undertake such research and to ensure the suitable provision of highly skilled professionals for the future job market. Despite significant investments in interdisciplinary training, there is much confusion about what it entails, how it should be implemented or why it is so highly valued.

In the present study, I ask: what is the rationale behind the perceived value of interdisciplinary research and training, and how does it affect students’ experiences of their PhD? I observed students in an interdisciplinary doctoral programme to understand how they experience their PhD training, and I examined the UK policy documents that have led to this movement. This research uncovered how interdisciplinary science is performed by the students under study and was compared with the aims and expectations of government policies.

The results of this research indicate that policies encourage interdisciplinarity through promises for a better future but that, in practice, it is difficult for universities and students to implement this mode of working.
Acknowledgements

I am heavily indebted to my supervisors for their help and support in producing this thesis and making the journey a rich and pleasurable experience. I could not have wished for a better team.

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This research project would not have been possible without the cooperation of staff and students at CDT-OPTIMA, who made me feel welcome, gave up their time to participate in the study, and allowed me to experience many of their academic activities.

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<tr>
<td>CDT</td>
<td>Centre for Doctoral Training</td>
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<tr>
<td>ESRC</td>
<td>Economic and Social Research Council</td>
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<tr>
<td>EPSRC</td>
<td>Engineering and Physical Sciences Research Council</td>
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<tr>
<td>MRC</td>
<td>Medical Research Council</td>
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<tr>
<td>PhD</td>
<td>Doctor of Philosophy degree</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<tr>
<td>REF</td>
<td>Research Excellence Framework</td>
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<tr>
<td>STEM</td>
<td>Science, Technology, Engineering, Mathematics</td>
</tr>
<tr>
<td>STI</td>
<td>Sociotechnical Imaginary</td>
</tr>
<tr>
<td>STS</td>
<td>Science and Technology Studies</td>
</tr>
<tr>
<td>UK</td>
<td>United Kingdom</td>
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<tr>
<td>UKRI</td>
<td>UK Research and Innovation</td>
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<tr>
<td>UUK</td>
<td>Universities UK</td>
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Chapter 1 Introduction

1.1 The interdisciplinary turn in UK policy

The United Kingdom (UK), like many other countries, aspires to develop its economy by producing knowledge and technology (BEIS, 2017; Carayannis and Campbell, 2005, pp.ix-x) with the conviction that effective policies enable the successful exploitation of emerging technological opportunities (Aghion et al., 2009). This position has led the UK Government to emphasise solution-oriented research in policy to "tackle the most complex and pressing challenges of government, industry and wider society" (UK Government, 2020) and to commit to supporting collaborations between universities and businesses to boost productivity in high growth sectors (UK Government, 2021a). This research approach often demands that researchers combine knowledge from different disciplines to address specific practical aims and is known as interdisciplinary research (Griffin et al., 2006; van Rijnsoever and Hessels, 2011). In other words, scientific research is expected to be highly innovative, strengthen technological innovations and designed to maximise and showcase "exciting, novel, and adventurous impacts" (REF, 2020), through strong collaboration between industry, science, and government (UK Government, 2022, p.6).

For a nation that relies on technological progress for prosperity, knowledge, know-how, and skills more generally equate with "fuel for growth" (BIS, 2016)\(^1\), and the past expansion of universities has been seen as a success

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\(^1\) BIS is the name for the UK Government's Business, Innovation and Skills, now known as the Department for Business, Energy and Industrial Strategy (BEIS).
for the training of new intellectuals and researchers. Thus, to build on its ambitions, the UK Government needs universities to continue growing capacity by training highly talented researchers to strengthen the UK’s position as a “collaborative science superpower” (BEIS, 2021, p.32). The UK Council for Graduate Education’s 2022 report (Smith McGloin and Wynne, 2022) corroborates the idea of “support for interdisciplinary and applied doctoral research to deliver economic and/or societal impact”. However, the report mentions the challenge for universities to “accommodate the ‘messiness’ of working across universities, disciplines and sectors” (p.65), perhaps reflecting the fact that 71% of institutions reported discipline-based doctoral programmes (p.54). It is in this context of a policy turn to interdisciplinary science and education that current doctoral students are working to enhance their intellectual abilities through their training and life at university, intending to create opportunities for productive future selves in a profession.

While science and technology advancements are generally recognised to help boost a nation’s performance in economic growth, there is no single key to success (Taylor, 2016, p.18). Whereas interdisciplinary research is often linked to collaboration, innovation and integration of disciplinary knowledges in the policy rhetoric, there is a lack of evidence that it leads to innovation in practice (Blackwell, 2009). Moreover, the policy turn to interdisciplinarity affects how academic work proceeds in universities – it requires a shift away from the disciplinary norms, values, and organising models that have underpinned academic life for the last two centuries. So, although the UK
Government’s emphasis on innovative science and research is clearly aimed at growing the nation’s prosperity, the reasons behind policies that promote interdisciplinary research are less obvious, and the challenges associated with interdisciplinary training and their effects on the students’ experiences are not well understood.

1.2 Purpose of the study

The significance of the UK doctorate in the research landscape is firmly under scrutiny from the government and evidenced by the number of reviews and reports released in the last five years: reviews of doctoral education from two research councils (EPSRC, 2021; Tazzyman et al., 2021), the Augar report (Augar, 2019), the investment in additional postgraduate research in bioscience in 2019 (Skidmore and Warmann, 2019), Universities UK’s report into the value of higher education\(^2\), and the Council for Graduate Education’s new UK doctoral education strategy (Smith McGloin and Wynne, 2022). The recommendations and findings of these reports will be discussed in further detail in section 3.4.

Interdisciplinary science is on the rise in the UK (Technopolis and SPRU, 2016; van Noorden, 2015) and requires the training of new generations of scholars to sustain this mode of research (Boden et al., 2011; Jacob, 2015; Lyall and Meagher, 2012). This new form of doctoral training is delivered within universities, alongside the more prevalent and traditional disciplinary

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\(^2\) Graduate employment: its limits in measuring the value of higher education (2022) [Last accessed 31/03/2022].
doctorates, and presents challenges for its implementation, specifically in relation to established academic norms (Castán Broto et al., 2009), curriculum content (Holley, 2009a) and the socialisation of students (Weidman et al., 2001, p.5). Yet, interdisciplinarity is extensively discussed in academia (Peseta et al., 2010, p.100) and seems widely accepted as an exciting endeavour without adequate scrutiny of the underpinning logics and consequences for its implementation in doctoral training.

1.2.1 Aims of the study
It is the UK Government’s contention that interdisciplinary doctorates, focussed on delivering highly skilled and innovative scientists, will boost the country’s technological progress and the nation's welfare through increased economic productivity (UKRI, 2022). This vision of higher education is at odds with the traditional goals of universities to train intellectuals and, I will argue, creates confusion around the role of the doctorate and society’s expectations of academic research. While the UK policy agenda links interdisciplinarity with innovation, the relationship is often taken for granted, and how interdisciplinary training affects students’ experiences has, up until now, not been examined (Blackwell, 2009). This study aims to investigate the relationship between educational policymaking, interdisciplinary research training, and the role of universities in society. I will later argue that tensions identified in this research primarily stem from the differing visions of the state and academia, which pursue their respective goals as two distinct institutions.
1.2.2 Objectives of the study

The present study examines the rationale behind the perceived value of interdisciplinary research training from the perspective of the UK Government and a large cohort of interdisciplinary doctoral students. Following an extensive review of the existing scholarly literature, two phases of research were conducted simultaneously; a desk-based exercise to mine policy documents and an educational ethnography phase during which I immersed myself in the research settings to carry out observation, interviews, and informal conversations with participants (see chapter 4). These two stages provided insights into, respectively, why and how interdisciplinarity is promoted as a strategy in UK policy and a rich understanding of the practices of my participants.

1.2.3 Research questions

The main research question guiding this research is as follows:

How are UK interdisciplinary policy intentions enacted in doctoral training?

The main research question was broken down into three further questions:

1. What specific practices are enacted by the students in the interdisciplinary doctoral programme under study?
2. How do these practices fit with the traditional idea of the university?
3. What are the differences between interdisciplinarity in practice and policy?
1.3 Research context

The 1970s calls for interdisciplinary science and training (e.g. CERI, 1972) failed to establish interdisciplinarity as a mode of knowledge production in higher education (Weingart, 2018). However, the late 1980s saw a renaissance of interdisciplinarity (Klein, 1990, p.180). In the UK, interdisciplinary science has been highly influenced by political rhetoric of the so-called "knowledge economy" (BIS, 2016; Powell and Snellman, 2004). In this context, interdisciplinary science is perceived to be superior to disciplinary research in tackling complex problems (Klein, 2004) and addressing economic concerns of science (Aghion et al., 2009) and education (Becker, 2011). Further influences on the ascendancy of interdisciplinary research include researchers' own interests, universities' internal drivers, sociocultural challenges, and the evolution of academic disciplines (e.g. Lyall et al., 2015a). One of the main challenges for universities has been to address the political concerns for the applicability of university research and requirements to demonstrate that research can be directly useful for society. Over time, efforts to increase the usefulness and impact of research were discussed as translational research, dissemination research, knowledge brokerage, knowledge translation, knowledge transfer, knowledge exchange, and implementation research (Caves and Lueling, 2021), and are most recently known as “research impact” (McKenna, 2021). The research impact agenda has produced much contention among scholars, including the way it is woven through ideas of interdisciplinarity, and this will be discussed in more detail in section 3.5.
1.3.1 Interdisciplinary doctorates

The doctorate is the highest achievable qualification in higher education (Kelly, 2017, p.1; Park, 2005; 2007b, p.4) and prepares students for future employment in academia and various other sectors. Today's traditional doctoral programmes in the UK include a three- to four-year research period, including skills training at university. Upon satisfactory completion and examination, the most frequently awarded degree is Doctor of Philosophy, commonly abbreviated as PhD (Park, 2005). Doctoral education remains one of the "least well understood areas of university higher education" (Kemp et al., 2014), and the last few decades saw significant changes to the UK doctorate to meet the needs and interests of students and other stakeholders. There now exists a host of "new variants" of doctorates (Park, 2005), some of which can be undertaken at the student's place of work, as is the case with some professional doctorates, while others emphasise requirements for interdisciplinary and collaborative research.

This study investigates a new type of doctorate called a PhD with integrated studies, which will be introduced in section 1.3.2. This specific type of doctorate emphasises the training of doctoral graduates in interdisciplinary research practices and is a direct result of the interdisciplinary turn in policy for technological progress, discussed in section 1.1. As will be discussed in section 1.3.2, these interdisciplinary doctoral programmes contain particular elements and requirements in addition to those found in traditional PhDs.

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3 Common types of doctoral programmes in the UK [https://www.vitae.ac.uk/doing-research/are-you-thinking-of-doing-a-phd/what-is-a-doctorate-1/common-types-of-doctoral-programme-in-the-uk](https://www.vitae.ac.uk/doing-research/are-you-thinking-of-doing-a-phd/what-is-a-doctorate-1/common-types-of-doctoral-programme-in-the-uk) [Last accessed 29/03/2022].
because they are based on an instrumental view of academic knowledge for economic purposes and exist to fulfil the government’s ambitions for "the UK as a global science superpower and an innovation nation" (UKRI, 2022). To achieve these political goals, a highly skilled workforce is required, hence the investments in interdisciplinary PhD programmes of the last decade (Demharter et al., 2017).

In the UK, as elsewhere, interdisciplinary doctoral programmes are undoubtedly becoming a trend, especially in areas of research that aim to address socially relevant issues and promise new innovations (EPSRC, 2018; Jacob, 2015; Technopolis and SPRU, 2016; Vanstone et al., 2013). As we shall see in chapter 2, the existing literature on interdisciplinary research often labels this type of research as "novel", arguing for its role in finding solutions to complex problems and for the adequate preparation of future scientists (Davies et al., 2010, p.xiii). In contrast, the perceived superiority of interdisciplinarity over disciplinary research has been criticised due to a lack of evidence (Jacobs and Frickel, 2009). Meanwhile, interdisciplinary doctoral studies focus on the nature of and changes to the PhD (Baschung, 2016; Bernstein et al., 2014), issues of supervision (Lee, 2008), the purpose of the PhD (Hoyne and Alessandrini, 2016; Shaminini and Spronken-Smith, 2019), and the effectiveness of doctoral programmes (Golde, 2015; Nyquist, 2002).

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The UK Government’s emphasis on interdisciplinary science for economic productivity in specific priority fields has firmly put the responsibility on universities to deliver these policy goals, which are enshrined in specific funding opportunities advertised by the research councils. However, doctorates are regulated by academic norms and, most importantly, for this discussion, are tightly connected to the disciplinary structures of most UK universities. The traditional doctorate, conventionally understood and metaphorically conceived as an apprenticeship (Gilbert 2009, p.54), is an intellectual activity designed to produce and reproduce a specific body of knowledge or discipline (Heilbron, 2004, p.24; Taylor, 2018) and disciplinary academics (Boud and Lee, 2008, p.2; Golde, 2006). The PhD is still intricately bound with, and reproductive of, academic disciplines, which grant knowledge credence and may work to undermine current policy calls for innovative and productive research (Letiche and Lightfoot, 2014, p.4). Disciplines are considered important in the social organisation and structures of universities and for the training of students (Jacobs, 2017; McCulloch, 2012). Moreover, it has been found that in many countries, the professionalisation of academics tends to reinforce mono-disciplinarisation and, therefore, discourage interdisciplinarity (Griffin et al., 2005a). Thus, the

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5 In the UK, the research councils are governmental bodies grouped under the umbrella of UK Research Innovation (UKRI - [https://www.ukri.org/about-us/](https://www.ukri.org/about-us/)), itself part of the department for Business, Energy and Innovation Strategy (BEIS). Although the UK government is the focus of this study, it should be noted that UK universities raise income from diverse sources of funding in addition to governmental funds. Directed funding for doctoral training is also available from academies and charities, and international research councils such as the European Commission (see [https://royalsociety.org/topics-policy/projects/uk-research-and-european-union/role-of-eu-in-funding-uk-research/](https://royalsociety.org/topics-policy/projects/uk-research-and-european-union/role-of-eu-in-funding-uk-research/)). As part of a worldwide trend, these institutions also offer directed funding for interdisciplinary research with similar rationales as the UK (Allmendinger, 2015) and are not treated differently or separately in this discussion.
disciplinary structures of most universities are thought to prevent the institutionalisation of interdisciplinary education (Lindvig et al., 2017).

Realising technological progress from academic research is not a straightforward process (Taylor, 2016, p.30), but the UK Government continues to invest in interdisciplinary doctoral training programmes in the hope of harnessing the potential of research to boost its economic productivity. For some scholars, this has resulted in significant changes for universities and the research system and the added pressure to satisfy the interests of multiple stakeholders (Austin, 2002). The literature concerning interdisciplinarity at the doctoral level presents mixed messages about the promotion and effects of this type of training and points repeatedly to the need for further empirical research (Lattuca et al., 2017; Manathunga et al., 2006; Shandas and Brown, 2016). Consequently, there needs to be an urgent discussion on why this mode of research and training is widely endorsed without evidence of its efficacy and influence on students and universities. There is currently a danger that the promotion of interdisciplinary education will continue to be advocated through policies and funders without further consideration of consequences for academia and students. This study critically examines how higher education and policymaking practices shape each other and contributes to ongoing debates by providing empirical evidence around academic knowledge production and policy assumptions (Albert et al., 2019).
1.3.2 Research setting

This study is based on ethnographic research undertaken within the OPTIMA Centre for Doctoral Training (CDT-OPTIMA, thereafter) based at the University of Edinburgh and the University of Strathclyde. CDTs are a specific model of interdisciplinary postgraduate education in which the government has invested to prioritise certain research areas and train the leaders and researchers of the future (e.g. EPSRC, 2018). Students undertake a four-year doctoral research programme in medical optical imaging with business studies to address healthcare problems through innovative products or services and are required to undertake a mandatory three-month placement in industry in or around their third year of study.

Medical optical imaging is a minimally or non-invasive investigational technique that uses light to obtain detailed images of organs, tissues, cells and molecules for medical diagnosis and treatment of various conditions\(^6\).

The degree is formally owned by the School of Chemistry at the University of Edinburgh. However, the degree programme is delivered jointly by the School of Chemistry, College of Medicine and Veterinary Medicine, School of Engineering and Business School at the University of Edinburgh, and the Department of Pure and Applied Chemistry, Strathclyde Institute of Pharmacy and Biomedical Sciences, the Department of Physics and the Hunter Centre at the University of Strathclyde. Typically, students’ training spans multiple areas of engineering, optics, chemistry, biology and business,

\(^6\) Information retrieved from the National Institutes of Health (USA), online at https://www.nibib.nih.gov/science-education/science-topics/optical-imaging [Last accessed 24/04/2023].
with a supervisory committee including at least one supervisor from Edinburgh and one from Strathclyde. One supervisor is drawn from the physical sciences (physics, chemistry) or engineering and another one from biomedical science.

Students begin their programme by familiarising themselves with the field of optics through a course entitled “Build Your Own Microscope”. According to the course learning outcomes, students will be able to understand how to build and optimise a functional microscope, understand the function of each component in a microscope system and the theory behind spectroscopy, and understand techniques of Raman, fluorescence and absorption spectroscopy. During their first year, students are also introduced to ethics and regulatory processes in translating innovation, which also cover good clinical practice. Finally, students also begin developing their knowledge of the physical and biomedical sciences in the laboratories and through literature reviews in order to meet the specific needs for their projects. Research projects are defined by the supervisors with past examples of research such as: “fluorescence guided surgery”, “validation of pre-existing and novel imaging agents for lung cancer”, and “raman spectroscopy for the study of radiation response in brain tumour cells”.

CDT-OPTIMA was set up in 2014 in response to EPSRC’s funding calls for the UK’s largest investment in postgraduate training in engineering and physical sciences (EPSRC, 2018). The doctoral programme involves research across the physical and biomedical sciences to tackle issues in
optical medical imaging and is, therefore, inherently interdisciplinary (at least in the sense that it involves more than one discipline). Upon completion, students graduate with a PhD with integrated studies, which includes the equivalent of one year taught masters modules in Entrepreneurship and Innovation spread across the first three years of the doctoral programme. While graduates are not awarded a master’s degree, they need to pass a minimum of 140 credits with a pass mark of at least 50% and attain an average of at least 50% overall for the 180 credits of the taught programme and pass the PhD viva to be awarded the PhD with integrated studies. Students who pass the PhD viva but do not pass the required taught components are eligible for the award of a standard PhD, and those who fail the PhD viva may be eligible to submit for a Master of Science by research.

The business studies part of the programme aims to produce entrepreneurial scientists capable of translating their research findings into real-life applications. Thus, CDT-OPTIMA programme addresses EPSRC's strategy to play a vital role in delivering research and innovation that will "drive the global economy in the 21st century". 

CDT-OPTIMA recruits, through international competitive application, one cohort of about twelve students per year from a range of scientific disciplines, which is spread across Edinburgh and Strathclyde uniformly. Students are geographically dispersed – in addition to being hosted in two

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8 Disciplines may include but are not limited to neuroscience, biochemistry, physics, biomedicine, chemistry and veterinary medicine.
large Scottish cities, numerous research centres are involved, and students are allocated to various laboratories, depending on the scope of their research and their primary supervisors' location. Students are required to travel between campuses weekly and use two study hubs, one in each university. This study occurred across both universities.

CDT-OPTIMA students are encouraged to cross between academia and industry in at least three ways: 1) the mandatory work placement in industry, 2) interactions with industrial partners during invited talks and presentations, and 3) interactions with NHS patients and staff. Some students also worked with staff from the Healthcare Technology Accelerator Facility (HTAF)\(^9\), who provide live projects for students’ work on the integrated masters. Students also cross borders within the university through interactions with different disciplines for their research, the Business School for the innovation and entrepreneurship segment of the PhD programme, clinical staff, and the public engagement officer.

1.4 Research framework

In the absence of any prevailing consensus on what interdisciplinarity brings to research and many unresolved questions concerning doctoral training worldwide, this thesis asks what the perceived value of interdisciplinary training is and how it affects postgraduate students' experiences during their PhD programme.

\(^9\) HTAF website: [https://www.ed.ac.uk/healthcare-technology-accelerator/](https://www.ed.ac.uk/healthcare-technology-accelerator/) [Last accessed 09/08/2022].
Scholars of Science and Technology Studies (STS) have examined the making of knowledge by scientists in depth but have rarely investigated the making of scientists during their training at universities (Sørensen and Traweeek, 2022, p.202). STS methods and concepts have been underutilised in studies of interdisciplinarity (Silvast and Foulds, 2022b, p.4) and educational research (de Freitas et al., 2017). Interdisciplinary doctoral training is often discussed in the existing literature in terms that decontextualise it from educational policy (Allen, 2017) and with too few empirical studies of interdisciplinarity in practice (Lattuca et al., 2004). The central proposition of the present study is that interdisciplinary skills are learned in practice during doctoral training, which comprises many activities connected to knowing and doing (Gherardi, 2015). Interdisciplinary doctoral training is enacted through relationships, interactions, and languages and embodied by participants in their active participation in practices (Augsburg, 2014).

Because of the diversity of definitions of interdisciplinarity in policy and the literature (Vienni-Baptista et al., 2022), I approached fieldwork with a focus on the everyday practices of CDT-OPTIMA students rather than a pre-specified conception of the term to answer research question 1 (what specific practices are enacted by the students in the interdisciplinary doctoral programme under study?).

Understanding interdisciplinarity through practices (what), actors (who), and enactment (how) (Jarzabkowski et al., 2015; 2016) also allowed a partial...
response to research question 3 (what are the differences between interdisciplinarity in practice and policy?) by contrasting what happens in doctoral training with how policies describe what should happen. Research question 2 (how do these practices fit with the traditional idea of the university?) brings in the idea of the university as traditionally disciplinary based and asks how interdisciplinary practices fit in this context. It should be noted here that the “idea” of the university is used in this context to avoid a fixed account of universities, whereas each has a unique “multiple cultural configuration” (Alvesson, 2013a, p.205). The university is not a homogenous field and is taken here to be structured into specialised sub-fields or disciplines, which are interdependent (Papilloud and Schultze, 2018, p.347). Further discussion of the context of UK universities can be found in section 2.1.

In the present study, the university is conceptualised as a social field formed by the knowledge-based practices enacted by actors (individuals or groups), who thereby establish the way of doing things based on shared understandings about the purposes of the field and relationships to others in the field (Fligstein and McAdam, 2011, p.9). Hence, the study involves a shift from individuals’ practices to practices and how they are enacted by their practitioners (Spaargaren and Lamers, 2016, p.4). Thus, it is possible to think of interdisciplinarity as a change in the traditional disciplinary practices of universities and involves a transformation of some elements of practice (Shove et al., 2012b, p.140). “Practices” are at the heart of the present study and are examined through the lens of practice theory.
Practice theory has seen a resurgence in the past two decades, especially following the publication of *the practice turn in contemporary theory* by Schatzki et al. (2001). The renewed interest in practice theory is relatively recent, but its origins can be traced back to scholars as diverse as Marx, Heidegger, Wittgenstein, Giddens and Bourdieu (Grootenboer et al., 2017, p.3), Goffman and Foucault (Jonas et al., 2017, p.xv). Such diverse works and approaches signal divergent perspectives on a practice approach. Since it is not possible to talk of a practice theory as a unified body of theories, an alternative approach is to think of a family of theories, all concerned with praxeology, the theory of human action or practice (Rigg, 2014).

The success of the turn to practice is not without contention and challenges. For instance, the multiple and varied historical origins of practice theory and how to recognise a practice or obtain evidence of its enactment have been presented as problematic by Schmidt (2018) and his work on socio-informatics. Adding to such confusion is the expanding use of “practice(s)” outwith a practice theoretical framework (Schatzki, 2012) and the expansion of the conceptualisation of practices. For example, Antonacopoulou (2008) found five different notions of practice - as action; as structure - language, symbols, tools; as activity system; as social context; and as knowing - and identified different definitions. This variety of approaches may confuse readers and demand that scholars be more explicit in their understanding and use of the term “practice”. Practice theory has been contextualised in the present study to address practices in the “education complex” (Kemmis *et al.*, 2014a, p.50), and this interpretation is discussed in the following section.
1.4.1 Practice theory in this study

The seminal work of Schatzki et al. (2001) was followed by the works of Shove et al. (2012b), Kemmis et al. (2014c), and Nicolini (2017), among the many contemporary scholars involved in developing a “theory of practice” in their diverse fields (Spaargaren and Lamers, 2016, p.6). In particular, Shove et al. (2012b, p.82) proposes a slim-line version of practice theory in which practices involve the integration of three elements: materials, competence, and meaning (ibid., pp.22-24). From this perspective, knowledge and know-how are considered practices rather than objects to be acquired. In the context of interdisciplinary doctoral training, students learn by participating in the practices of other practitioners (peers, supervisors, staff), and especially how to go on in these practices (Schatzki, 2017, p.34), thereby reproducing existing academic practices and the idea of the university, while enacting specific visions of what interdisciplinary research is.

This research framework has helped produced several key insights regarding this specific type of PhD programme (chapter 8) and points to the importance of interactions with a community of peers during doctoral training for the effective socialisation of students. One of the key contributions of this thesis stems from linking expertise with learning practices, which has led to the argument that CDT-OPTIMA students lack role models in order to develop their own professional identities. Additionally, this thesis argues that definitions of interdisciplinarity are further complicated when the concept is applied to research as a broad label to fit with funders’ requirements. In this case, optical medical imaging is shown to be a multiple disciplinary field, or
an interdiscipline, as it does not necessitate the integration of various
disciplines. The empirical evidence points to research practices that are best
described as “bricolage” – the incorporation of some elements of knowledge
and expertise from diverse disciplines (section 8.3.1). This insight has led to
a definition of interdisciplinarity through the metaphor of the chimera (section
8.3); a mythical creature that figuratively describes the challenges of
describing the concept and the difficulties in performing interdisciplinarity.

From a policy perspective, I argue (section 5.4), that interdisciplinary
research training has been politicised and used as a political instrument for
building an Education UK brand and remaining competitive internationally.
This insight was also found in the UK universities market their
interdisciplinary doctoral programmes through an economic and competitive
perspective (section 6.4.3).

1.5 Structure of the thesis

This chapter has introduced the context for the study, the issues involved,
and the research questions this thesis aims to answer. The UK Government's
policies to make Britain a global superpower in science and innovation
promote collaborative and interdisciplinary research. New generations of
researchers are being trained in interdisciplinary science to supply the
leaders and scholars who will be tasked to deliver the government's visions
of the future. However, doctoral training is increasingly under pressure from
the interests of the multiple stakeholders it aims to satisfy, and
interdisciplinary research lacks consistent definitions and purposes. This
study sought to generate empirical evidence in response to current tensions brought about by the rise of interdisciplinary practices in universities, as identified in the existing literature. The study's central question is: what is the rationale behind the perceived value of interdisciplinary research and training, and how does it affect doctoral students' experiences at university?

Overall, chapter 2 seeks to explore current understandings of interdisciplinarity, how it is enacted in universities and its place in doctoral training. In order to achieve this, it has been necessary to curate a body of knowledge that integrates insights from educational research and scholarship on interdisciplinarity. Consequently, the literature presented in this chapter is diverse and originates in multiple disciplines and fields of research, reflecting the current lack of understanding around the training of interdisciplinary researchers at universities. The chapter will explore the features of interdisciplinary research and training to uncover how it is conceptualised and defined in existing scholarly work. Section 2.1 focuses on the academic context with a brief survey of the historical origins of universities and the doctorate, as well as the role of academic disciplines. Interdisciplinarity, its definitions, its relationship to other modes of knowledge production, and other academic practices are the subject of section 2.2. This section emphasises that while the UK doctorate strives to remain relevant to the training of future scientists, the implementation of interdisciplinary doctorates in the disciplinary structures of universities is problematic (Lindvig et al., 2017). Although on the rise, interdisciplinary research is not the norm (Technopolis and SPRU, 2016) in UK universities and presents challenges
for students' professionalisation process, identities, and future career prospects. These concerns bring about questions regarding the role and mission of universities that strive to hold onto their historical heritage while modernising to accommodate and enact educational policies for the twenty-first century. Section 2.3 explores existing studies that have conceptualised academic research, universities, doctoral training, or interdisciplinarity through the theoretical framework of practice theory and STS studies. The section serves to introduce practice theory as used in current research to demonstrate its applicability for examining doctoral work and understanding interdisciplinary research training.

Chapter 3 builds on concerns around the role of universities in the wider society by exploring links between science and government. A policy concern about the value of investments in science has strategised scientific knowledge as an instrument for the welfare of society. Universities have always made contributions to the wider society, but the government now expects more specific benefits in return for investment in scientific research, thus focusing university practices on commercial activities. The section discusses the relationship between universities and the rest of society through the political rhetoric of innovation and technology, visions for doctoral training and how policies and politics affect the production of science.

Chapter 4 describes the methodological choices made in the present study for researching interdisciplinary doctoral practices. The chapter describes the educational ethnographic approach to focus on the unique experiences of
doctoral students during their interdisciplinary programme. The method for data analysis section of the chapter reflects the challenges encountered when paying attention to multiple stakeholders and their relationships. The section offers a detailed discussion on mapping as data analysis strategy and its implementation in the study. The chapter includes a section on the limitations of the approach, especially in terms of the situated nature of practices, and a reflexive discussion on the position of the researcher.

Chapters 5 and 6 present the empirical findings of the research based on an orientation to the future. Chapter 5 explores students' perspectives on their futures and expectations from an interdisciplinary doctorate. The discussion includes students' motivations for undertaking a PhD, the doctorate as a commodity for the future, and students' views on the integrated business and entrepreneurship masters. Overall, chapter 5 addresses the question of the perceived value of interdisciplinary doctoral training and students' experiences. Chapter 6 explores the policies and politics behind technological progress and claims that higher education should enhance the future welfare of society. The chapter offers different stakeholders' perspectives – the government, CDT-OPTIMA, and the university – to show how they coproduce collective agendas that promote change in practices. Overall, chapter 6 argues that different understandings of interdisciplinarity are based on different promises, expectations, and visions of and about the future. Thus, chapter 6 is concerned with the formulation and enactment of educational policies and strategies and science-society relationships.
Chapter 7 is the final empirical chapter of the thesis and explores how interdisciplinary doctoral research is enacted in practice, especially how it relates to the disciplinary organisation and norms of academic work. Chapter 7 addresses the question of how interdisciplinary doctoral training is embedded in universities and the challenges behind institutionalising such practices.

Chapter 8 is a discussion and synthesis of the empirical chapters that aims to answer the main research question – what is the rationale behind the perceived value of interdisciplinary research and training, and how does it affect students' experiences of their training? By contrasting the political rhetoric behind calls for collaborative and interdisciplinary science with the academic practices in universities, the thesis presents the differing visions of two very distinct institutions that are, nonetheless, both concerned with the future of the nation. In this chapter, interdisciplinarity is described using the metaphor of a chimera, reinforcing the view that it is not the norm in academia and pushes students to practise in a space of marginality. In this respect, I argue that CDT-OPTIMA's field of research in medical optical imaging is best seen as an interdiscipline rather than interdisciplinary. Furthermore, the discussion extends to show that, in this case and as an ideological driver, interdisciplinary doctoral training is an investment aimed at improving the circulation of knowledge between academia and industry and, as such, is partly involved in changing academic practices.
Chapter 9 presents a reflective conclusion of the thesis findings, the contributions to knowledge, a list of recommendations, the strengths and limitations of the present study, and potential directions for further research on interdisciplinary doctoral training.
Chapter 2 Interdisciplinary scholarship

Higher education systems continue to evolve to remain relevant to contemporary society and globalisation pressures worldwide (Brooks et al., 2022, p.2). Nations face challenges in educating a growing and increasingly diverse student population (Brooks and O’Shea, 2021, p.1) in a climate characterised by reduced funding (Jones, 2022, p.50), employers’ concerns over the readiness of graduates (Phillips, 2010), and political concern for the future (Amsler and Facer, 2017). In an era of the so-called “knowledge economy” (BIS, 2016), where knowledge is thought to be a crucial resource for economic progress (Peters and Humes, 2003), the science system, and especially universities, are seen as playing an essential role for the delivery of future skilled workers (Durazzi, 2019), technological innovations (Jacob, 2021; UK Government, 2021a), and to provide societal benefits (Bornmann, 2012).

Thus, universities are expected to respond to high expectations and to implement policies by changing their various practices. Importantly for the present study, the training of doctoral students, as an essential component for addressing the visions of the government for the innovation ecosystem, now includes new variants of PhD programmes alongside the more traditional academic training activities usually associated with the doctorate (Park, 2005). In order to encourage technological progress and economic productivity (UK Government, 2020), the UK Government and its research
councils have funded a series of specific doctoral training programmes with interdisciplinary training to produce interdisciplinary scientists who will be highly skilled and capable of delivering the government’s vision. The Centre for Doctoral Training Optima (CDT-OPTIMA), the site of the present study, is an example of a new model of doctoral training that seeks to address the perceived deficits of UK universities: it aims to train students in collaborative and interdisciplinary research to translate scientific knowledge and is a direct response by universities to government’s aims to harness benefits from academic knowledge.

These new PhD programmes demand new academic practices from academics, administration, and students yet remain unexamined in the UK and warrant scrutiny for an understanding of how they influence the next generation of researchers. Interdisciplinary training (and research) is also fraught with many challenges encapsulated by Augsburg (2014) and Pohl and Hirsch Hadorn (2008) when they ask: how does one become a transdisciplinary researcher? In order to address the research question (section 1.2.3) of how are UK interdisciplinary policy intentions enacted in doctoral training, it is important firstly to understand the long traditions behind the history of universities and the role of disciplines before examining the definitions of concepts such as “interdisciplinary” and “transdisciplinary” and how they relate to different modes of research and academic cultures. This examination provides the background for the evolution of universities and doctoral training and points to difficulties for interdisciplinary doctoral training concerning careers and individual professional identities when institutions
and students are under pressure to meet political requirements and expectations.

The following sections review the UK academic historical context of the PhD with a discussion of the role of disciplines before turning to interdisciplinarity, other modes of knowledge production and the embedding of interdisciplinarity in universities (section 2.2). Section 2.3 addresses the existing literature surrounding practice theory as the theoretical framework used in this study.\(^{10}\)

2.1 The UK academic context

2.1.1 A brief history of UK universities and the doctorate

[H]ow many institutions that existed then [1530] can still be found now. The authors identified sixty-six in all: the Catholic Church, the Lutheran Church, the parliaments of Iceland and of the Isle of Man—and sixty-two universities. (Carnegie Council, 1980, cited in Damrosch, 1995, p.18)

Universities are social institutions that have perdured throughout the centuries (Cronin, 2016, p.1), as stated in the quote above. In general, the advent of universities is a debated issue (Heller, 2021, p.1; Rüegg, 2010, ch.1). Still, Oxford is often recognised as the first university founded in the UK around 1096, followed by Cambridge in 1209 (Boliver, 2015). Together with St Andrews (1413), Glasgow (1451), Aberdeen (1495), Edinburgh (1583) and Marischal/Aberdeen (1593, now Aberdeen), these universities are often labelled as the “ancient universities” (Harlow, 2020, p.34). The UK, as a

\(^{10}\) A note on the methodology used to compile the literature can be found in section 4.4.
whole, is highly characteristic of a hierarchical system of higher education: some institutions, mainly the newer universities created after 1992, can be said to have low status, while the ancient universities, typically research-intensive universities, enjoy a much more elite status with a more significant part of the resources concentrated within. This study took place across the universities of Edinburgh and Strathclyde (founded in 1796 as the Anderson’s institution11). While the University of Edinburgh is considered an ancient university, the University of Strathclyde is classed as a “plateglass” (Harlow, 2020, p.35) university (meaning it obtained its status in the 1960s).

These long-standing institutions are culturally significant and carry distinguished reputations (Cronin, 2016, p.2), reflecting their importance and early beliefs throughout Europe that more knowledge would improve society (Otterspeer, 2008, pp.6-13). As producers of learned professionals for church and state, universities historically produced an elite (Anderson, 2003, p.114) and enjoyed a special status in society. However, such a long history has brought universities many challenging times and successions of ups and downs (Cronin, 2016, p.2), even if they continue to enjoy a status of high prestige to this day.

European higher education is thought to be predicated on three separate models, which have influenced many national education systems as they

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11 University of Strathclyde, Glasgow online
have evolved since their inception (Sam and van der Sijde, 2014). According to Sam and van der Sijde (2014, p.896), these models were:

- The Humboldtian model of Germany - based on academic freedom and research-based learning.
- The Napoleonic model of France was vocational and intended to prepare students for their professional lives outside academia.
- The Anglo-Saxon model of Britain provides a broad educational base and a “basic feature of personality development through liberal education”.

There is now a recognition that, although the models still exert some influence on how to train students and produce research, European universities seem to have moved to a single Anglo-American model focused on “competition, marketisation, decentralisation and a focus on entrepreneurial activity”, with national differences according to governmental policies and priorities (Brooks et al., 2022, p.2).

The function of universities was not without dilemmas, even in medieval times. For example, Lynch (2003, p.6) describes the aims of the key players in the creation of Edinburgh’s college as “confused and sometimes self-contradictory.” There is no doubt that nowadays, universities are “the most important institutional medium – for conserving, understanding, extending, and handing on to subsequent generations the intellectual, scientific and artistic heritage of mankind” (Collini, 2012, p.198).
That universities and society interact and influence each other in complex ways is a commonly accepted idea among scholars (Rüegg, 2010, p.11). Keepers of old traditions, “cathedrals of learning” (Cronin, 2016, p.2) or “bastions of liberty” (Otterspeer, 2008), universities have been the subject of criticism and are sometimes derisively described as “ivory towers” (Shapin, 2012). The ivory tower metaphor conveys the special status of the university, the intellectual pursuit of knowledge, and the idea that it is cut off from society. The metaphor is widespread worldwide, from Brazil (De Castro Alcântara et al., 2016) to South Africa (Buckley, 2012) and also refers to the inequalities of access to and opportunities in universities, which are thought to exclude many social groups (Ramdeholl, 2013). The idea of “value” and what society stands to benefit from investments in higher education is of utmost importance for understanding how universities are seen from the outside. For example, Benneworth (2019, p.80) discusses universities’ irresponsible behavioural repertoires that lead to public value deficiencies such as failure to allow publics to shape university engagement activities, benefit hoarding, directing teaching resources to other activities, avoidance of long-term investment (including staff contracts), and excessive spend on marketing. It is perhaps unsurprising, then, that even if universities were never ivory towers (Shapin, 2012), the idea that they stand outside, or apart, from society is very much an enduring belief, often emphasised in everyday language that opposes universities to the “real world” (Björck and Johansson, 2018).
The university as a house of knowledge which trained few students to supply society with educated professionals is outdated as it is now expected to deliver innovations, ensure the employability of students and increase the pace at which knowledge is made available to society (Sørensen and Traweek, 2022, p.159). This market orientation of policies has led to the notion of “academic capitalism”, whereby universities are involved in the maximisation of economic profits (Münch, 2020) and the commercialisation of public science (Fini et al., 2018). The pursuit of the translation of knowledge into economic activity has given rise to the concept of “the entrepreneurial university” driven by metrics (Etzkowitz, 2016) and new public management control (Deem et al., 2007). While the term “entrepreneurship” may refer to multiple conceptualisations (Mars and Rios-Aguilar, 2010), it is understood in this thesis as a general concept that refers to the commercialisation of research, as well as university initiatives, to respond to policy demands. Thus, the entrepreneurial university also aims to foster an entrepreneurial spirit in students through new programmes, incentives and innovation management centres such as Edinburgh Innovations\textsuperscript{12}. The implementation of business and entrepreneurship studies in UK universities has grown exponentially in recent times (Gray et al., 2020, p.146), prompting some scholars to describe universities as businesses focussed on the production and consumption of goods, led by heavy bureaucratic controls (Rosso, 2019a).

\textsuperscript{12} Edinburgh Innovations, online https://www.ed.ac.uk/edinburgh-innovations. [Last accessed 29/09/2022].
The early doctorate, conventionally understood and metaphorically conceived as an apprenticeship for entry into academic posts (Gilbert 2009, p.54), was an intellectual activity designed to produce and reproduce a specific body of knowledge or discipline (Heilbron, 2004, p.24) and disciplinary academics (Boud and Lee, 2008, p.2). These early centres for learning (Collini, 2012, p.23) offered scholars spaces to freely pursue knowledge through systematic and disciplined investigation (Moore, 2019, p.66). The arrival of the UK research PhD (from Philosophiae Doctor in Latin) is thought to have signalled the modern era of organised training research and was already subject to political forces (Simpson, 1983), despite universities’ presumed position as “free from state control” (Moore, 2019, p.67). Moreover, the doctorate, as a specific academic practice in which new generations of scientists and scholars are produced, is bounded with the way universities are understood in wider society (Kelly, 2017) and as constructed in policy (Brooks et al., 2022, p.3).

The last couple of decades have brought many changes to the research training landscape in UK universities, including its role and purpose (Poole, 2009) and to universities. Scholars in the Higher Education field call these changes “momentous” (Green, 2008) or refer to “a sea of change” (Park, 2005), and concerns include the diversity of degrees (Bourner et al., 2001) and the rise of strategic science (Rip, 2004) among others.
2.1.2 The modern doctorate(s)

The rapid expansion of the UK higher education system in the latter half of the 20th century manifested in at least three ways: growth of student numbers, of higher education institutions, and of the proportion of age-relevant students (Trow, 2007, p.245). What was once a small number of privileged “apprentices” in a few subjects based in a few universities has now exploded into a mass higher education system (Bernstein et al., 2014, p.7; Scott and Callender, 2017, p.141). This massification of education is thought to be the source of immense changes in universities worldwide (Altbach, 2013), such as the diversification of degrees and increased international competition (Altbach, 2017, p.1).

Even though countries, institutions and disciplines have influenced the evolution of their higher education systems differently through specific national policies, similar patterns have been observed throughout the world (Bloch et al., 2018; Meyer, 2022), especially in Europe. The European Higher Education Area and the Bologna process13, more specifically, have encouraged a policy convergence across European countries (albeit with divergence in implementation) and, in doing so, have influenced current understandings of what it means to be a student (Brooks et al., 2022, p.2).

Despite the UK voting to leave the EU in 2016 (and cessation of trading with

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13 The European Higher Education Area (EHEA) is a collaboration of 49 countries (including the UK) that cooperate to ensure the quality and comparability of their higher education systems through agreement and adoption of reforms discussed through a forum known as the Bologna process. See http://ehea.info/ and https://education.ec.europa.eu/education-levels/higher-education/inclusive-and-connected-higher-education/bologna-process for more details [Last accessed 05/12/2022].
EU partners since 2020), UK universities continue to participate in the Bologna Process and its aims for policy coordination of higher education and its underpinning of a political economy for higher education (Barrett, 2017, p.28).

In the UK, the early disciplinary PhD remains the norm (Park, 2007a, p.28) but is now accompanied by new forms of doctoral degrees: PhD by publication, new route PhDs\(^{14}\) \textit{(ibid.)}, Doctor of Science (DSc), Doctor of Letters (DLitt) (Park, 2007b, p.4). A number of professional or practice-based doctorates are also available\(^{15}\): Doctor of Education (EdD), Doctor of Business Administration (DBA), Doctor of Social Science (DSocSci, SScD or DSS), Doctor of Professional Studies (DProf, ProfD, or DPS), Doctor of Clinical Psychology (ClinPsyD, DClinPsy). The above list of doctoral degrees is not exhaustive but shows changes in the PhD, which besides including the traditional research model, also includes professional training.

These new variants reflect long-standing concerns with the doctorate, particularly in terms of the preparation of students for taking up positions either in academia or other sectors. In the USA, Golde and Dore (2001) conducted a national study on the experiences of doctoral students in the arts and sciences and found that students are well prepared for carrying out research but not for other academic tasks. This view is reflected by Wulff et

\(^{14}\) New route PhD scheme is similar to CDT-OPTIMA. It is a four-year PhD that includes taught elements and professional training alongside the research project.

\(^{15}\) List made up from information available on Vitae website https://www.vitae.ac.uk/doing-research/are-you-thinking-of-doing-a-phd/what-is-a-doctorate-1/common-types-of-doctoral-programme-in-the-uk [Last accessed 16/06/2022] and a Google search for UK doctoral programmes on 16/06/2022.
al. (2004, p.61), who found overall that “graduate programs did not purposely plan systematic opportunities for their [students] developmental progression as teachers and researchers”, although they also point to differences between the disciplines. In the UK, a landmark report to the government by Roberts (2002, p.111) noted that “PhD students are also seen to be poorly prepared for work in either academia or business” and sparked debates over the value of research skills to the economy (Richardson, 2007, p.75). The Roberts report highlighted many concerns over PhD studies, especially the lack of transferrable skills for non-academic employment, and engendered a range of initiatives to counteract these deficiencies (Souter et al., 2007, p.15). Coate and Leonard (2002) reinforce the idea that the research councils found “the PhD provides neither a rigorous enough methodology training for those who go into academia, nor an appropriate initial and continuing professional development for those who go outside” but also point to the fact that there is little research on which to base these assertions. More recently, Sharmini and Spronken-Smith (2019) reported that the PhD does not develop sufficiently relevant skills for research careers.

Universities and doctorates must, therefore, be understood in the broader context of the “social, economic and political market for knowledge and expertise” (Hinchcliffe et al., 2007, p.5). Changes in the doctorate are also driven by academia for capacity-building purposes (Bieta et al., 2011), an example of which is provided in Mills (2006) and his recommendations and strategies for sustaining the development of the social science research base in the UK.
The present study is based at the University of Edinburgh and the University of Strathclyde, both currently considered to be research intensive universities located in Scotland. In the UK, educational and research policy matters are devolved across the four nations (England, Wales, Scotland and Ireland), presenting some differences for universities and students. However, this study examines the experiences of participants in a Centre for Doctoral Training (CDT), which is centrally funded by the UK research councils (UKRI), so a distinction between the separate systems is not useful for this discussion.

The site of this study is CDT-OPTIMA doctorate, a PhD with integrated study, a forty-eight-month period in which students undertake research as in the conventional PhD with taught elements from the Business School that make up a master's degree in entrepreneurship and innovation. The master's degree is a requirement for the obtention of the PhD, but the qualification is not awarded. Students graduate with a PhD with integrated study, which, unlike other doctorates, does not indicate a specific discipline and is interdisciplinary due to the nature of the optical imaging field. These new types of doctoral training are delivered in universities that traditionally organise research and teaching through disciplines (Lindvig et al., 2017). Scholars (for example, Jacob, 2015) have shown in empirical and analytic research that interdisciplinarity introduces challenges to the higher education system and the students. Subtler shifts have also happened due to the implementation of new doctorates in UK universities and have changed how doctoral training is understood. Once a matter of “postgraduate research”
that emphasised outputs, activities and relationships, the training of students is now the domain of “doctoral education” with an emphasis on preparing students for employment in the labour market as per employers’ requirements (Boud and Lee, 2008, ch.1).

Before exploring interdisciplinarity and doctoral training in the UK context, it is necessary to discuss the disciplinary specialisation of knowledge in academia, the subject of section 2.1.3.

2.1.3 Disciplinary specialisation

Herein lies one of the major crises of modern knowledge. It is what I have called the Humpty Dumpty problem. […] Try as we may, we are no more able than all the king’s horses and all the king’s men to put our knowledge together again for coping with the whole real problems of the world. (Easton, 1991, p.12)

Disciplines play a profound role in academic life for teaching, research, assessment, and publication practices (Kreber, 2009, p.19) and exert “a powerful influence in reward systems and in the creation and maintenance of academic agendas” (Henkel, 2005, p.173). Academic disciplines are continually evolving (Trowler, 2012a, p.5), and there is no consensus regarding a basic terminology (Moran, 2010, p.vii), producing a “kaleidoscope of disciplinarity” (Sugimoto and Weingart, 2015). Nonetheless, it is custom in interdisciplinary studies to examine the historical division of knowledge into disciplines to understand interdisciplinarity (Chettiparamb, 2007; Lattuca, 2001, p.23; Moran, 2010, p.2; Repko, 2008, p.53).
The scholarship on academic disciplines is extensive and spans multiple research fields, traditions, different levels of education and reflects diverse and particular interests such as curricula, teaching, learning and assessment. For this discussion, I follow Aram (2004) and consider disciplines to be broad intellectual domains, such as economics or physics. Moreover, I believe Jacobs (2014, p.27) adds an important detail to the definition of disciplines by pointing out they are institutionalised in universities, meaning they are a form of norm or convention. Accordingly, disciplines are intellectual domains that are established as conventions in academia, in contrast to the problematic attempts to institutionalise interdisciplinarity in this pre-dominantly disciplinary structure (Calvert, 2010, p.201).

Nonetheless, the function of disciplines in the university cannot be overstated, especially in the context of education, and the importance of disciplines as technologies of education is examined in the following section.

2.1.4 Student socialisation in disciplines

With strong cultural and conventional properties, disciplines produce their own body of specialist knowledge and practices and serve to divide intellectual domains (Jacobs, 2014, p.4). In order to become competent members of an intellectual domain, students require socialisation into the norms and expectations of the disciplinary culture they are entering (Austin and McDaniels, 2006, p.440).

Doctoral training takes place in multiple layers of culture, including the academic department, the discipline, the institution, and the profession,
which individuals have to identify, negotiate and develop in order to acquire a career identity (Holley, 2011). These activities help the socialisation of students, defined as the process “in which an individual interacts, integrates, and learns the values, skills, attitudes, norms, and knowledge to effectively participate in a group” (Johnson et al., 2020, p.316). As the extensive research from Weidman and DeAngelo (2020) has shown, the socialisation of students in higher education begins at the undergraduate level and through to graduate studies. During their education, students acquire not only knowledge but also skills and values through anticipatory, formal, informal and personal processes of interaction with peers, supervisors and other academic staff and students (Weidman et al., 2001). Thus, learning is understood in this thesis as a social process that relies on observation and social interactions with others (Baker and Lattuca, 2010; Eyler, 2018; Lattuca, 2002). In researching the socialisation of doctoral students in chemistry and history in the USA, Gardner (2007) found socialisation processes essential for students’ success and require clarity of expectations, direction from advisors, support from staff and peers, and a sense of self-direction. Socialisation is thus crucial for both students, in becoming a member of the “tribe” as Trowler et al. (2012) describe, and for universities who strive to train the researchers of the future. In particular, the concept of socialisation of students contributes to how researchers understand and assume their professional roles and, thus, deserves close scrutiny (Austin and McDaniels, 2006). Disciplines are an intrinsic part of learning in universities, providing “cultural repertoires of practices” (Holley, 2011),
“cultural tools” (Lattuca, 2002) and “research repertoires” (Ankeny and Leonelli, 2016), all important factors in the socialisation of students in disciplines.

Disciplines provide cultural repertoires that, according to Holley (2011), doctoral students engage with and practice in their daily activities to learn how to become particular kinds of people. Becoming a physicist, for example, does not solely rely on the acquisition of knowledge but on acquiring certain elements of the culture in order to become a member of the community of physicists. According to a practice theory perspective, the elements of the culture are not objects to be acquired but, rather, behaviours, beliefs and assumptions are resources that result from an active engagement with the community of practitioners and peers. Participation is shaped by students’ own beliefs, values and prior experiences, thus, cultural tools are used and interpreted in selective ways and can be used strategically. Therefore, students possess agency in the way in which they acquire cultural elements, meaning that students and cultures are mutually constitutive.

Lattuca (2002) used a sociocultural theory approach to cultural tools, such as languages and material artefacts, to show how they function as cultural mediators that shape the way students interact with the world once appropriated. In this perspective, disciplines include five components:

The **substantive component** (which includes the assumptions, variables, concepts, principles, and relationships of the discipline); the **linguistic component** (the symbolic language that allows elements to be identified and relationships defined and explored); the **syntactical component** (the search for
organizing processes around which the discipline develops); the **value component** (commitments about what is worth study and how it should be studied); and the **conjunctive component** (the discipline’s relation to other disciplines). (Lattuca, 2002, p.715, my emphasis).

As Lattuca (2002) argues, these components form part of the practices of doctoral education, by which participants learn to participate more knowledgeably in a community of practitioners and are, therefore, critical to an engagement with scholarly practice. In particular, as will be discussed in section 2.3.5, the five components highlighted above form the basis for gaining expertise in a discipline and stress the importance of tacit knowledge that is gained through immersion in a community.

Ankeny and Leonelli (2016)'s research repertoires are similar to the cultural repertoires and tools identified above and encompass:

> Well-aligned assemblages of the skills, behaviors, and material, social, and epistemic components that a group may use to practice certain kinds of science, and whose enactment affects the methods and results of research (Ankeny and Leonelli, 2016, p.20).

Because the characteristics of disciplines, such as methodologies, epistemologies and ontologies, are so instrumental for understanding the socialisation of students (Boden *et al.*, 2011), they present particular issues for interdisciplinary training (Buanes and Jentoft, 2009) on both a structural and cultural level (Borrego *et al.*, 2014). The formation of professional researchers has been found to rest on the notion of what Shulman (2005) called “signature pedagogies”. Through research, scholars have identified specific signature pedagogies teachers use to convey specific methods to
students (Reiff et al., 2002). In university chemistry education, for example, research efforts continue to deliver detailed accounts of how best to support students, devise activities and guidelines (Seery et al., 2019), how to support laboratory activities (Agustian and Seery, 2017), or to discuss alternative lecture formats (Seery, 2015). Like most other countries, the UK educational system rests on a model of disciplinary specialisation, first in subjects at school level (e.g., English, mathematics, science, physical education), then through academic disciplines in undergraduate study at universities. By the time students start on a doctoral programme, they have become enculturated in a discipline and have had limited or no exposure to interdisciplinarity (Gombrich and Hogan, 2017, p.545).

In empirical research, signature pedagogies have been shown to relate to the development of students’ identities along disciplinary affiliation (Abbas et al., 2016; Chick et al., 2012, p.4; Golde, 2007; Gravelle and Fisher, 2012). Disciplines, like professional training, define what is to be learned, how to arrive at this knowledge, and sets of beliefs about the world, which map onto the three distinct apprenticeships proposed by Shulman (2005): the cognitive (habits of mind), the practical (habits of hand) and the moral (habits of heart). Shulman also emphasised the pervasiveness of signature pedagogies as they are found across institutions (also Crookes et al., 2020) and are implemented so as to leave the disciplines intact (Woeste and Barham, 2006). Professional identities have been shown to matter in collaborations between health and social care workers by Best et al. (2021), who concluded that “thinking like others” is the most challenging aspect of teamwork.
Overall, the literature agrees that a focus on signature pedagogies allows students to experience habits of mind and practices they will need in their future professional lives (Boix Mansilla and Chua, 2017; Woeste and Barham, 2006) through interactions with peers and role models.

The work of Mossop et al. (2013) on the hidden curriculum contributes to the understanding of signature pedagogies further by pointing out that not all learning is formal. They define the hidden curriculum as “a set of influences that function at the level of organisational structure and culture” that includes “role models, rules and regulations, the use of institutional slang and resource allocation” (p.135). The hidden curriculum in doctoral training is especially important since a common signature pedagogy among all doctoral training programmes is the practice of experiencing research; students are not so much taught how to do research, but they experience first-hand the practice of carrying out research. Much of what is learned during the PhD is not solely confined to elements of the disciplines but is also the process of working in a higher education institution, its structure, culture and governance. Thus, the hidden curriculum is also made up of a multitude of implicit and informal rules that are part of the students’ socialisation process and required for success in their programme. These rules are specific to each programme, discipline or university, but they can be found across all graduate education and can only come to be understood through the students' participation in the activities of research.
2.2 Interdisciplinarity

Historical context

Frank (1988) and Jacobs (2014) noted the call for interdisciplinarity began almost as soon as disciplines were established, and there is some evidence that interdisciplinarity functions as a critique of disciplines (Klein, 1990, p.95). Much criticism has been levelled at the disciplines, for example, their limitations for producing research in a complex modern world (Klein, 2004), acting as silos impeding communication across fields and stifling innovation and economic growth (Jacobs, 2014, pp.13-26). Frodeman (2014) argued the disciplines lack societal relevance and accountability due to their excessive specialisation. Damrosch (1995, p.23) and Miller (2020) contend the specialisation of disciplines is an obstacle to addressing complex social problems that became discernible at the turn of the 20th century. However, this was not a new problem. Possible dangers resulting from an overspecialisation, or fragmentation of disciplines, were identified relatively early in scholarly work and arose between the 16th and 19th centuries (Klein, 1990, pp.20-21). The search for unifying scientific concepts has been an ideal since the campaign for the Unity of Science in the 1930s and 1940s (Klein, 2018, p.5). While the unity of science concept is complex and can be understood differently (Tahko, 2021, p.1), it is certainly relevant to some aspects of interdisciplinary science, which can be seen as a search for the unity of knowledge by integrating different disciplinary perspectives, or as a response to the disunity of science.
A multitude of accounts about the world, both competitive and compatible, persist in scientific explanations, leading to “scientific pluralism” (Mitchell, 2002). This plurality may be contrasted with the monistic perspective based on a one-world hypothesis: reality is complex and scientific models capture different aspects of the world that can be added up to explain one reality (Hvidtfeldt, 2018b, p.145). In this case, the monistic assumption accentuates the requirement for unifying concepts, while the pluralist view focusses on the disunity of science, and both may lead to the false belief that adding-up different disciplines will produce a “complete picture” (Silvast and Foulds, 2022b, p.9). Problems arise from this interpretation and give credence to individuals who maintain that universities are ivory towers made up of “hundreds of disciplinary islands, each speaking a separate language, with minimal connections among islands” (for example see Wilson, 2012).

Empirical evidence based on citation indices has, in fact, revealed a high degree of communication between disciplines and multiple science map overlays have been produced for different sectors, universities and disciplines (for example, Leydesdorff and Rafols, 2009; Rafols and Leydesdorff, 2009; Rafols et al., 2010). Figure 1 is a visualisation of how disciplines engage in a given topic and reveals many connections rather than separate disciplinary islands.
In scientometric studies, patterns of citations across disciplines are used as a proxy for determining the level of interdisciplinary research, and, despite problems of classification, different techniques reveal tight connections between disciplines (Porter et al., 2007). However, Porter et al. (2007) point out that science is getting modestly more interdisciplinary, drawing mainly from neighbouring fields (also Porter and Rafols, 2009). Jacobs (2014, p.84) warns against relying too heavily on citation patterns, which may simply be a result of electronic access to literature, but also argues the volume of cross-citations is too large to be ignored. The view of academic disciplines as involved in the division of labour in universities is generally widely accepted, but the idea of disciplines as strict borders around intellectual fields is highly contentious (Jacobs, 2017, p.35). Indeed, as the above maps show,
disciplines may best be described as porous (Osborne, 2013, p.91). Claims of a historical disciplinary hegemony remain elusive (Schaffer, 2013, p.60).

By contrast, many researchers who have experienced interdisciplinarity often report working between or across disciplines (Castán Broto et al., 2009) or at the intersections between disciplines (Fletcher and Lyall, 2020), also known as interstitial spaces (Barry and Born, 2013; Lindvig et al., 2017) and this poses a problem of incommensurability. It is clear there are no common measures that allow the comparison of different disciplinary theories (Harris, 2005, p.3). As Hacking (1983, p.66) remarked, theories speak different languages and inhabit different worlds, they cannot be compared, nor can they be translated into each other. This issue is known as “incommensurability” in the philosophy of science, particularly from a Kuhnian perspective (Biagioli, 1993, p.211; Hacking, 1983; Harris, 2005; Holbrook, 2013; 2018). Incommensurability is relevant to interdisciplinarity because if disciplines have no common views on problems or if they offer incompatible perspectives, integration is not guaranteed (Politi, 2017). Similarly, Holbrook (2018) points out this problem affects interdisciplinary communication when theories do not share a vocabulary or a set of standards. Communication across disciplines is a significant issue of concern in the literature and remains a major challenge for scientists who collaborate (Crowley et al., 2016; Klein, 2014; Strober, 2011b). The issue of incommensurability may be eased by the proximity of disciplines, referring to the degree of overlap between two approaches (for example, disciplines that require laboratory work), or may be heightened by the distance between disciplines like social
sciences and physics. However, there remains an issue that proximate disciplines may not yield revolutionary insights and distant disciplines may be overwhelmingly difficult to integrate (Hvidtfeldt, 2018a).

The present study shows that interdisciplinary students who are supervised by mentors outside their first discipline, especially in the early stages, are faced with the same difficulties, although this is not discussed in the literature (see section 7.2.2).

Among the current debates, key issues are relevant to doctoral training: firstly, disciplines are described as barriers to collaboration and interdisciplinarity (Klein, 1993, p.185), and secondly, there is a tendency for interdisciplinary and collaborative research projects to involve neighbouring disciplines that are thought to be better able to communicate than distant disciplines (Porter and Rafols, 2009). The level of diversity or coherence of disciplines drawn on interdisciplinary research influences aspects of consensus and integration among the various fields (Rakas and Hain, 2019), as well as citation impact (Yegros-Yegros et al., 2015).

Definitions

The term “interdisciplinarity” may have emerged in the early twentieth century in New York when the Social Science Research Council’s members attempted to promote research that would involve two or more disciplines (Frank, 1988), but this mode of knowledge production was not new. It is thought working across disciplines dates back to Plato (Holley, 2009b, p.6; Klein, 1986, p.409), although it may be best to talk about “precursors” to
interdisciplinarity as this orientation was not mainstream (Choi and Richards, 2017, p.40). In this long history, interdisciplinarity has evolved into multiple understandings and practices (Vienni Baptista *et al.*, 2019, pp.7-8) - which I will address in the following few sections.

The existing literature on interdisciplinarity is plagued with a multiplicity of definitions and unresolved problems of terminology (Lattuca, 2002; Robinson, 2008), pointing to a lack of consensus over a universal definition (Huutoniemi *et al.*, 2010; von Wehrden *et al.*, 2018), and conveys a “spectrum of experiences” (Lyall, 2019b, p.4). However, there are some commonalities among scholars of Interdisciplinary Studies and the most cited definitions of interdisciplinarity, namely: it is research that involves more than one discipline, it requires integration of knowledge, and addresses problems that are beyond the scope of one discipline (Klein *et al.*, 2022, p.2; Newell, 2001; Repko, 2008, p.12). For Vienni Baptista *et al.* (2019), consensus over definitions of interdisciplinarity and transdisciplinarity include “interdependence, cooperative labour, and mutuality, all oriented towards shared purposes”, hinting at the relational characteristics of team science. A helpful definition of interdisciplinarity was provided by the National Academy of Sciences (2005):

> Interdisciplinary research 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 specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of
This definition is thought to be broad and inclusive of the multifaceted nature of interdisciplinarity (Lyall, 2022, p.13) and, in the context of the present research, provides a good starting point for thinking about how interdisciplinarity is enacted in doctoral training. Yet, I have found this all-encompassing definition problematic for studying the training of new interdisciplinary scientists. For example, this definition presents some contested concepts, which are left unexamined and raises further questions about how students are trained. I examine two characteristics meaningful to the present study: individual and collaborative interdisciplinarity, and integration.

**Individual and collaborative interdisciplinarity**

Team-based and single-investigator research have distinct organisational and relational characteristics (Vermeulen *et al.*, 2013). Interdisciplinarity is often associated with collaborative work across disciplines (for example, Jacobs and Frickel, 2009), but a single investigator working with different disciplines also performs a form of interdisciplinarity. Differences between individual and teams undertakings have not been explored in the existing literature (Hess, 2018; Sørensen, 2012), and I have, to date, found no references to distinctions applied in interdisciplinary research training, begging the question: is it possible for a novice researcher to carry out interdisciplinary research individually? In other words, can an individual student engaged in research and training be considered an interdisciplinary
researcher? While various researchers have studied the necessary skills and competences necessary to become a successful interdisciplinarian (Augsburg, 2014; Fam et al., 2017; Lyall et al., 2011b, p.35), they all assume that interdisciplinarity requires collaboration, reinforcing the words of Bowen et al. (2021) that “nothing researchers do in their own areas is adequate without the insights and expertise of other disciplines.”

Moreover, University College London and Durham University stated that collaborations should be grounded in expertise and in the interactions between disciplinary experts rather than interdisciplinary experts (Taylor, 2013). These statements bring into question the interdisciplinary training of doctoral students (what is the academic purpose?), as well as the perennial issue of when to start training students in interdisciplinary research, especially when careers are at risk (discussed in section 7.2.4), given junior scholars are discouraged from going into interdisciplinary work (Lyall, 2019b, p.3).

Moreover, collaboration is a vague term used to describe cross-disciplinary and cross-institutional work. Collaborations are often associated with “academic engagement” and the transfer of knowledge from universities to industry, where engagement can include contract work, networking, and other informal activities with non-academic organisations (Perkmann et al., 2013). Despite the rapid growth of university-industry collaborations in the last twenty years, there is no evidence they result from a policy push (Calvert and Patel, 2003). Yet, significant reviews into the UK research and
development ecosystem continue to emphasise university-industry collaborations and the need for “a whole range of scientific disciplines” (Lambert, 2003, p.11) because this type of collaboration provides “a myriad of benefits to their participants” and is increasingly recognised as essential for the innovation ecosystem (Dowling, 2015, p.2).

In doctoral training, collaborative skills are commonly known as “transferable skills” (Germain-Alamartine, 2018), a hotly debated issue in higher education, especially regarding which types of skills should be developed and for what aims (Denicolo et al., 2016; OECD, 2012, p.34). Transferable skills may also include enterprise training to increase venture formation, which can be implemented through diverse strategies (Phillips, 2010).

CDT-OPTIMA students undertake their doctoral research as a solo endeavour, experience interactions with industry during their three-month mandatory placement and business training is delivered as part of the integrated master’s in business and innovation. The present study will later examine empirical findings of students’ perceptions of their placements, what they stand to gain from the process, and their perceptions of the transferable skills they gained. The study will also examine the gathered evidence to determine whether collaborations are part of the training and, if so, their role and who they involve. This is a crucial part of making sense of how interdisciplinary doctorates fit in the university and how they are perceived in society and the labour market, where they often hold symbolic power (Tholen, 2017, p.166).
Integration

The concept of integration is neither straightforward nor easy to identify (Repko, 2008, p.302); degrees of integration can vary (Klein, 2006), and so can methods (Klein, 2012), as do disciplinary perspectives (Clark and Wallace, 2015). Thus, the integration of disciplinary knowledge is a contested idea even if Repko (2008, p.116) claims the centrality of integration to interdisciplinary approaches is reaching consensus among interdisciplinarians. Klein (2006) uses the metaphors of “bridge-building” and “restructuring”. Bridge-building is the most common and easiest type of integration, often oriented to practical outcomes and is about making connections between disciplines. Restructuring reflects a more radical form of integration with a new organisation of knowledge beyond the disciplines. Other scholars contend interdisciplinarity is not necessarily the result of an integrative-synthesis mode and have proposed alternatives such as the “subordination-service” and “agonistic-antagonistic” modes of interdisciplinarity by Barry et al. (2008). They define the subordination-service mode where the service discipline(s) counter a lack in the master discipline. The agonistic-antagonistic mode is not a synthesis of knowledge but a conscious criticism of the established disciplines and their limits.

On the other side of the argument, Lattuca (2001, pp.12-15) warns against emphasising disciplinary integration for two reasons. Firstly, from an educational perspective, any team-taught course is considered interdisciplinary, regardless of the level of integration in teaching, planning,
evaluation, and content. Secondly, Lattuca (2001, p.15) argues “for many feminists, poststructuralists, and postmodernists, the redefinition project is about dismantling disciplinary perspectives, not maintaining and integrating them.” Some literature argues that disciplines are a source of confusion when defining integration as there is no argument about what is being integrated (for example, Laurent, 2012). Similarly, while Holbrook (2013) argues that questioning the notion of integration “is almost heretical”, he also points out that for some scholars, a consensus towards integration is “chimerical” and asks: what exactly is being integrated? The National Science Foundation’s definition of interdisciplinarity discussed earlier stated interdisciplinary research is the integration of “information, data, techniques, tools, perspectives, concepts, and/or theories” (National Academy of Sciences, 2005). Therefore, understanding interdisciplinary research training through the concept of integration requires asking how many of these disciplinary features must be integrated (all, none, a few?) and how do we know when integration has happened? At the end of the scale, Grüne-Yanoff (2016) affirms that two disciplines can learn from each other without any integration, but this leaves unclear what has happened.

2.3 Logics of interdisciplinarity

It is commonplace in the existing literature to find references to assumptions regarding a link between interdisciplinary research and innovation (Barry et al., 2008; Miller, 2020). Some of these assumptions are explicitly and implicitly articulated by the UK Government, especially in the life sciences, where scientific knowledge is expected to help the UK become a “Science
Superpower” and lead the sector globally (UK Government, 2021b). I will return to the policy issues in chapter 3, which will examine the UK research landscape. While the links between interdisciplinarity and innovation are profuse in policy agendas (Lyall, 2019a, p.2), Blackwell (2009, p.10) identified a lack of empirical evidence into how interdisciplinarity might lead to innovation, whereas the link is often taken for granted in policies. Existing UK policies emphasise innovation with a focus on the adoption, diffusion and commercialisation of new tools and technologies (UKRI, 2022, p.24), whereas academic research may focus on innovative intellectual practices or techniques (Strang and McLeish, 2015) that may lead to higher research impact, normally measured through citation metrics (Okamura, 2019). Bibliographic citations are a highly contentious topic given different classifications in use (Rafols and Leydesdorff, 2009), indicators (Robinson-Garcia et al., 2018) and how authors choose to represent their research through typologies of interdisciplinarity (Klein, 2017, p.21). Thus, while policies suggest interdisciplinarity is associated with commercial innovation, this relationship is far from straightforward (Godin, 2006a). The premise that scientific knowledge can readily be translated into innovation is a much more complex and dynamic process (Pielke, 2007, ch.2) than a progressive advancement from research to applied science, design, manufacture, commercialisation and marketing (Brooks, 1994). The linear model has long been rejected in science studies, and it is recognised that innovations arise in unexpected ways and cannot be anticipated at the outset of a new interdisciplinary project (Blackwell, 2009, p.13; Wilson and Blackwell, 2013).
While not all interdisciplinary research aims to develop new products and services, there is often a taken-for-granted assertion that interdisciplinarity leads to innovation, especially in the policy rhetoric surrounding research and development, despite evidence that attempts to translate knowledge into innovation are complex and unpredictable processes. As MacKinnon et al. (2010) point out, research itself is mainly unpredictable as it is a process of discovery; thus, interdisciplinarity may arise, but there are no guarantees.

2.3.1 Interdisciplinarity and related terms

Another difficulty in defining the term “interdisciplinarity” (IDR) also exists in the persisting conflation of the term with its many derivatives, such as multidisciplinarity (MDR) and transdisciplinarity (TDR) (Silvast and Foulds, 2022b, p.10), making the term complex and ambiguous (Lyall et al., 2011b, p.11; Repko, 2008, p.17). Previous attempts to clarify differences between MDR, IDR and TDR have also focused on the level of integration of disciplinary knowledge, going from the lowest level of integration in MDR to high in TDR, where research may also involve non-academic participants or lay perspectives (Klein, 2017). Figure 2 presents a graphical summary of the differences between MDR, IDR and TDR.
### Figure 2: Some Differences between multi-, inter- and transdisciplinarity

<table>
<thead>
<tr>
<th>Multi-disciplinarity</th>
<th>Inter-disciplinarity</th>
<th>Trans-disciplinarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juxtaposing, Sequencing, Coordinating</td>
<td>Interacting, Integrating, Focusing, Blending</td>
<td>Transcending, Transgressing, Transforming</td>
</tr>
<tr>
<td>Low</td>
<td>Level of integration of the disciplines</td>
<td>High</td>
</tr>
<tr>
<td>Shared topic, communication, juxtaposition of perspectives, autonomy</td>
<td>Integration of disciplinary, insights, cooperation, interdependence</td>
<td>Problem-solving, implementation, collaboration between institutions and other actors</td>
</tr>
<tr>
<td>Problem type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple: agreement on problem and solution</td>
<td>Complex: conflict over solution</td>
<td>Wicked: Conflict over problem and solution</td>
</tr>
</tbody>
</table>
MDR, IDR and TDR show different characteristics and address different types of problems, but they all refer to research that encompasses two or more academic disciplines. Sometimes, the term cross-disciplinary is favoured as an umbrella term to designate such research in general, and there are calls to use this term as a general catch-all term for research practices that involves several disciplines (Silvast and Foulds, 2022a, p.11). For other scholars, interdisciplinarity and transdisciplinarity are already portmanteau words (Frodeman, 2017, p.4) used to talk about not – or more than – disciplinary research. Nevertheless, the distinctions proposed between MDR, IDR, and TDR presented in figure 2 allow a nuanced understanding of different modes of research, the relationship between researchers, researchers and communities, and researchers and research policies. It should be noted that the three terms are not always understood or used similarly across countries, with the UK preferring the term "interdisciplinarity" to the USA’s use of transdisciplinarity (Lyall et al., 2015b). Finally, it should be clear too that modes of research are continually evolving as they are enacted, and new definitions may be needed to denote these changes (Braun and Schubert, 2003).

2.3.2 Other modes of knowledge production
Some scholars argue the production of knowledge for practical purposes has increased since the late twentieth century as knowledge is seen as an essential resource for economic productivity and population well-being worldwide (Martin, 2003). Associated with this perspective is the concept of Mode 1 and Mode 2 research advanced by (Gibbons et al., 1994). Mode 1 is
associated with the traditional, disciplinary mode of basic and curiosity-based knowledge production, while Mode 2 indicates a shift in practices towards broader contexts of application and interdisciplinarity (Gibbons et al., 1994, pp.10-12). According to Nowotny et al. (2003), the shift from mode 1 to mode 2 is partly due to significant trends: the ‘steering’ of research priorities, the commercialisation of research, and the accountability of science.

The concept of Mode 2 has been widely contested and has not been found to be a convincing argument in the debates that oppose pure and applied research (Hessels and van Lente, 2008; Martin, 2012) and may be more a rhetorical tool for policy purposes than a fundamental shift in academic practices (Agar, 2017; Calvert, 2006; Martin, 2003). A good example of the pushback against the popularity of Mode 1 and Mode 2 thesis is the suggestion by Bresnen and Burrell (2012) that these have been poorly theorised and that the ancient mode of knowledge production – Mode 0 – is actually re-asserting itself. Bresnen and Burrell (2012) discuss the different modes of knowledge production from a historical perspective and extend the discussion to encompass their proposition for Mode 0, Mode 1.5 as discussed in Huff (2000) and Mode 3 as described in Huff and Huff (2001).

Based on my interpretation of the literature, a synthesis of the different modes of knowledge production is shown on the next page in figure 3. For clarity, I have shortened some of the descriptions used in the original works.
<table>
<thead>
<tr>
<th>Descriptors</th>
<th>Mode 0</th>
<th>Mode 1</th>
<th>Mode 1.5</th>
<th>Mode 2</th>
<th>Mode 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity trigger</td>
<td>Industrialist problem</td>
<td>Theoretic or empirical hole</td>
<td>Critical fault finding</td>
<td>Problem</td>
<td>Appreciation and critique</td>
</tr>
<tr>
<td>Participants</td>
<td>Cognoscenti, invisible, college</td>
<td>Homogenous subdiscipline</td>
<td>Diverse educationalists</td>
<td>Transdisciplinary</td>
<td>Diverse stakeholders</td>
</tr>
<tr>
<td>Goal</td>
<td>Solutions to specific problems for specific clients</td>
<td>Truth, theoretic extension, order</td>
<td>Continuing role for academics</td>
<td>Solution, improvement</td>
<td>Future good</td>
</tr>
<tr>
<td>Methods</td>
<td>Innovative inventions</td>
<td>Paradigm-based</td>
<td>Collective experience</td>
<td>Based on experience</td>
<td>Conversation</td>
</tr>
<tr>
<td>Activity site</td>
<td>Workshop, laboratory</td>
<td>Sheltered, ivory tower</td>
<td>Sheltered</td>
<td>Practice</td>
<td>Off-site but aware of practice</td>
</tr>
<tr>
<td>Time horizon</td>
<td>Immediate</td>
<td>Often unimportant</td>
<td>Not blue sky and not immediate</td>
<td>Often immediate</td>
<td>Immediate to very long term</td>
</tr>
<tr>
<td>Boundaries</td>
<td>Around proprietary ownership within the “household”</td>
<td>Disciplinary, pure/applied, institutional</td>
<td>Between consultants and academics</td>
<td>Transdisciplinary, often proprietary</td>
<td>Multiple modes of knowing</td>
</tr>
<tr>
<td>Beneficiaries</td>
<td>Dynasties</td>
<td>Individual scientists, professional groups</td>
<td>Professional discipline groups</td>
<td>Firms, government bodies</td>
<td>Society</td>
</tr>
<tr>
<td>Quality control</td>
<td>Power of money, return on investment</td>
<td>Elite-dominated peer review</td>
<td>Academics/solution buyers</td>
<td>Utility, efficiency</td>
<td>Community agreement</td>
</tr>
</tbody>
</table>

*Figure 3: Synthesis of different modes of knowledge production*
Figure 3 highlights that the descriptions of modes consist of categories that are not always mutually exclusive and might best be understood as theoretical constructs rather than models of how knowledge is actually produced. Moving across the table, for example, from Mode 0 to Mode 3, the modes of research are underpinned by different assumptions about who participates in research, why research is undertaken and who can benefit from the resulting knowledge. Bresnen and Burrell (2012) argue that mode 0 is very similar to mode 2 in that the research is often undertaken to offer immediate solutions to specific problems, and the benefits of knowledge are understood in utilitarian, economic terms.

2.3.3 Embedding interdisciplinarity in the university

The modern understanding of disciplines and disciplinarity emerged as a technology of the Enlightenment (Wellmon, 2015, p.7) with increasing fragmentation and formation of further disciplines thereafter (Repko, 2008, p.34). These disciplines now pervade all areas of academic life and generally structure universities, academic departments, and research and teaching activities (Kreber, 2009, p.19). Focusing on the organisation of universities through disciplines helps understand the concept of intellectual or academic “home” (Donald, 2009, p.48; Poole, 2009, p.50) as a concept that relates to academic identity and a sense of belonging to a community. Donald (2009) emphasises the notion of disciplines as providing homes with the broader university community and their role for learners. She argues academic homes guide learning, determine the domain of knowledge and the theoretical or conceptual structures of the mode of inquiry. Critically,
disciplinary formations provide students with academic role models who show them and represent how to perform skills, thereby inspiring and motivating students (Morgenroth et al., 2015). The home metaphor plays a part in the discourse surrounding interdisciplinarity, namely when it might be expected that once the project is over, some researchers may seek the safety of their traditional department boundaries – or “homes” (Klein, 1990, p.79; Lyall, 2019b, p.3). When disciplines are understood as providing homes for scholars and students, there is inevitably a threat of homelessness (Golde and Gallagher, 1999; Poole, 2009, p.57). This threat has crucial implications for researchers, especially in their early careers when they are urged to establish themselves in a discipline before undertaking interdisciplinary research or when trying to avoid risky effects on their careers (British Academy, 2016, p.9). The disciplinary structures and workings of universities, therefore, constitute a challenge to interdisciplinary practices and are often thought of as major barriers that continue to exert control over academic practices (Lindvig et al., 2017). For example, Henkel (2005) notes disciplines are the guardians of academic culture, nurturers of academic identity, they are strongly defended by elites and are “powerful influences in reward systems and in the creation and maintenance of academic agendas.” Researchers and scientists hold vested interests in aligning with a particular discipline, especially when competing for resources. In the science and technology studies (STS) literature, these practices of demarcation are known as “boundary-work” that delineate individuals’ expertise and exclude any rivals (Gieryn, 1983). Similarly, Calvert (2006) interviewed scientists and
policy-makers to examine their use of the concept of “basic science” (discussed in section 3.1) and found it a rhetorical device used to acquire resources and prestige. Disciplinary specialisation and basic science are part of academics’ repertoires and highlight the values and norms of academia, in direct contrast with interdisciplinarity and research that aims to provide practical solutions to problems. Unsurprisingly then, interdisciplinarity poses challenges for the training of scholars (Holley, 2015), not least because students tend to experience activities in a liminality state (Brandshaug and Sjølie, 2021) that entails a sense of marginality and of being “othered” (Lindvig, 2018).

Training for academic careers

A PhD was primarily a way to train the future academic workforce, but the academic job market is saturated and produces too many graduates for universities’ requirements (Larson et al., 2013). Accompanied by perceptions of requiring long working hours, the need to secure funding, and the move between institutions concur in a possible decrease in the appeal of academic career paths for students (Wellcome Trust, 2013). Moreover, institutional practices predicated on disciplines influence career trajectories and success (Dooling et al., 2017, p.582). Thus, a career outside disciplines is seen as very harmful and risky if tenure is the objective (Keck et al., 2017; Rhoten and Parker, 2004), yet interdisciplinary doctoral training and how it is experienced by students has not been well reported in the UK.
The existing research tends to focus on specific characteristics of interdisciplinarity in graduate school, such as why students choose to undertake this type of study (Moreno and Danowitz, 2016), the tension between IDR and the disciplinary structure of universities (Lindvig et al., 2017), the role of institutions in shaping the interdisciplinary careers of established researchers (Lyall, 2019b), the supervision and mentoring of interdisciplinary graduate students and junior postdoctoral researchers (Lyall and Meagher, 2012), and issues of socialisation (Boden et al., 2011). Alongside these issues, academic research paths are predicated on strong institutional incentives underpinned by disciplinary practices: publications in prestigious disciplinary journals, discipline-based jobs, and disciplinary identity (British Academy, 2016, p.28). In such a strong disciplinary environment, interdisciplinarity can sometimes be perceived with suspicion or stigma (Ledford, 2015) from a disciplinary perspective and prompts questions of expertise and legitimacy and therefore reinforces the idea of a risky career path (Callard and Fitzgerald, 2015, pp.11-12). Interdisciplinary research and training can hinder individuals when they seek to establish their academic credentials in an academic world that rewards specialised experts rather than “jacks of all trades” (Lau and Pasquini, 2008).

**Academic border control**

The space between the disciplines metaphor (Nash, 2008) is more often discussed in the existing literature, especially in STS, in terms of disciplinary divides (Mourad, 1997) that interdisciplinary researchers must cross. Such
cartographic metaphors (Sørensen, 2021) abound and include disciplines as boundary-work performers (Friman, 2010), creating borders that interdisciplinarity seeks to cross (Repko, 2008, p.22) or transgress (Friman, 2010). Disciplines are perceived as barriers to collaboration and interdisciplinarity (Klein, 1993, p.185). While it is generally recognised that disciplines serve to divide intellectual domains (Jacobs, 2014, p.4) and constrain researchers’ range of thoughts, methods and practices (Lyall et al., 2008), disciplines are also part of a norm of membership in academia and determine who has epistemic authority and power (Sørensen, 2021). The view of academic disciplines as involved in the division of labour in universities is generally widely accepted. Still, the idea of disciplines as strict borders around fields of intellectual inquiry is highly contentious (for example, Jacobs, 2017, p.35). Indeed, the description of disciplines as porous (Osborne, 2013, p.91) is also sustained throughout the literature and claims of a historical disciplinary hegemony remains elusive (Schaffer, 2013, p.60).

From the perspective that disciplines are well-established, entrenched, and persistent, they are seen as performing boundary work (Friman, 2010), following many cartographic metaphors found in STS (Sørensen, 2021). Disciplines are viewed as boundaries (Repko, 2008, p.22), island fortresses (Klein, 1990, ch.4), or barricades (Poole, 2009). However, disciplinary boundaries are vague, and members of a discipline are likely to disagree on its boundaries (Jacobs, 2014, p.33; Lattuca, 2001, p.244).

The cartographic metaphors used to describe disciplines are mainly an internal artefact of universities’ organisation and the peer review system.
(Holbrook, 2017, p.485). However, social institutions like universities exist within the wider society that relies on science and knowledge for its betterment. From this perspective, disciplines form boundaries against the outside world to keep out anyone who has not been certified as belonging to the community of scholars. Disciplines are instruments through which scholars seek to categorise who is in or out of science and who is in or out of specific fields of research. The idea of belonging in academia rests on membership in a scientific field through peer approval (Aldrich, 2014, p.14) and determines who has epistemic authority and power (Sørensen, 2021). In interdisciplinary research, the existing peer review system fails, and the quality of the research defies disciplinary standards and may thus be viewed as dubious (Huutoniemi and Rafols, 2017). The importance of belonging to a disciplinary community and being recognised as an expert in a field is crucial to understanding how interdisciplinary research is valued, or not, in academia and, hence, for career opportunities, especially when doctoral students wish to pursue an academic career path.

However, such perspectives tend to render academic disciplines as static and monolithic (Lattuca, 2001, p.25), hiding an implicit assumption there is little or no diffusion of ideas across disciplinary boundaries (Jacobs and Frickel, 2009).

2.3 Interdisciplinarity in practice

So far, I have summarised and discussed some of the pertinent literature that connects UK universities, students, interdisciplinarity and the political context
surrounding interdisciplinary doctoral training. This vast literature often refers to “practices”, academic, doctoral or research practices, and also points to the idea that academia and education are changing. In this section, I explore the inability of past research to adequately connect interdisciplinarity and education by discussing “practices” explicitly through the use of practice theory as the theoretical framework that underpins the present study. The reasons for this choice and previous uses of practice theory in existing studies are explored in the following sections.

2.3.1 Multiple academic practices

Talk of interdisciplinarity seems to be everywhere in higher education – no matter what the discipline, profession or field of inquiry. (Peseta et al., 2010, p.100).

Because interdisciplinary research does not belong to a discipline, researchers are (re-)producing an exponential growth of literature in all academic fields. A search on the University of Edinburgh online library (www.discovered.ed.ac.uk) for journals containing the word “interdisciplinary” returns 304 entries from Arts, Business, Environmental Sciences, Engineering Sciences, Health, History, Journalism, Languages, Law, Dance, Philosophy, Physical Sciences and Social Sciences. The increase in interest related to interdisciplinarity and the training of students is accentuated by the rise of interdisciplines, hybrid knowledge fields that draw on different disciplines, such as social psychology and biochemistry (Fuchsman, 2012). While interdisciplines may begin as interdisciplinary fields, they eventually grow to become a mainstream discipline (Repko, 2008, p.52), and do not
seek the integration or synthesis of the parent disciplines and cannot, therefore, be considered interdisciplinary (Fuchsman, 2012). In this sense, interdisciplines resemble multidisciplinarity (section 2.3.1). However, multidisciplinarity involves teams of disciplinary experts, each giving their own perspective on an issue, whereas an individual researcher can contribute to an interdiscipline by connecting aspects of at least two existing disciplines, thus participating in the further specialisation of their field of study (ibid.).

Vienni-Baptista et al. (2022) recently carried out a literature review of the academic literature and policy documents on definitions of inter- and transdisciplinarity and concluded it is important to accept the heterogeneity of definitions that point to a “family resemblance” concept of interdisciplinarity that includes related terms, as discussed in section 2.2.2.

Faced with this multiplicity of definitions, undertaking research on interdisciplinary doctoral training was always going to be a complex task, and I was aware from early on that privileging one definition over others would affect the study, depending on the chosen discourse and associated characteristics of “interdisciplinarity”. It was also evident that much of the literature focused on practices (academic, political, education, research) is under-theorised and taken for granted in ways that did not provide much insight or explanation of the phenomena under study (Hager, 2012). Practice theory seemed to offer a possible way of dealing with these intractable problems by focussing my attention on how interdisciplinarity was enacted in
CDT-OPTIMA rather than on what interdisciplinarity is. A practice theory perspective also seemed best positioned to deal with issues of how students learn across disciplines, changes perceived to be happening in universities and the PhD, and to carry out this study by exploring both the academic context and the policy landscape.

It should be noted that different approaches exist for the study of interdisciplinary education in the scholarly literature. Inevitably, choices had to be made about what to include or to exclude in the absence of a ready-made corpus. I tended to focus mainly on STS, higher education, policy, and interdisciplinary studies as the fields most associated with my research questions, and that could, therefore, provide some direction on how to proceed. This literature points to the disparity and lack of connection between the relevant fields and the lack of empirical evidence originating in the specific social, cultural and economic context of the UK, which I identified as “disconnections” and led me to the choice of a practice theoretical approach as an underused method in the field. Practice theory is examined and defined in the context of the present study with examples of past research in sections 2.3.4 and 2.3.5.

2.3.2 Disconnections

The training of doctoral students and studies of “interdisciplinarity” have traditionally been approached from separate academic fields that often emphasise the necessity for interdisciplinarity but that do not address the socioeconomic forces that shape education, prompting Allen (2017) to state
that interdisciplinarity is discussed in terms that decontextualise it from education and educational policy. In addition, higher education and extant disciplines have often overlooked doctoral students’ experiences (Cumming, 2009; Leonard et al., 2006), perhaps relating to what Enders (2005) noted as the unclear status of research training in the educational system. The field of higher education research seems to have suffered theoretically too; Hopwood (2018, p.10) gathered publications on the theory of doctoral education originated between 1980 and 2017 and mapped his findings from 200 articles, chapters and books (Hopwood, 2018, p.11), finding over 50 different theories in use. This work supports the earlier view from Lee and Boud (2008, p.11) that knowledge about doctoral education is partial and fragmented and may reflect the immaturity of the field (ibid. p.22). The study of higher education has, nevertheless, increased in the past few decades, despite a reluctance from researchers to study their own institutions (Altbach, 2014), which may have previously been pejoratively described as “navel gazing or simply bizarre” (Blaxter et al., 1998). The study of pedagogy and how students learn or how teachers are trained are more commonly situated outside the higher education area, in schools (Altbach, 2014). In agreement with Brew (2010, p.114), this thesis proposes that doctoral training should present “a picture of higher education where research, scholarship, teaching, and learning are viewed as part of one seamless whole.” I place studies of interdisciplinary doctoral education as a sub-set of this broader view of higher education that can, and should, embrace the diversity and co-existence of
multiple definitions of interdisciplinarity, generated in studies of cross-disciplinary research such as reported in Vienni-Baptista et al. (2022).

Interdisciplinary doctoral education has been studied through different approaches so far, focussing on specific characteristics of the process, for example, in cognitive studies through discourse (Bradbeer, 1999; Cuevas-Garcia, 2018), the psychology of interdisciplinary education (Gombrich and Hogan, 2017), and how students learn (Spelt et al., 2009). The educational and curricula fields worldwide have produced theoretical and empirical research on the best ways to educate students in an interdisciplinary manner at all levels of education, especially at the undergraduate level (Klaassen, 2018; Lattuca et al., 2004; Nikitina, 2006; Tripp and Shortlidge, 2019), with some studies in secondary school (for example Pountney and McPhail, 2017). Much of this research is concerned with the skills students need to acquire for a successful engagement with interdisciplinarity, accompanied by varying assumptions of what interdisciplinarity is, according to types of problems to be addressed, modes of inquiry or learning outcomes. The findings and insights proposed in this research lack empirical evidence from relevant students and often acknowledge and then dismiss the difficulties of defining interdisciplinary education and its implementation in disciplinary structures (discussed in section 2.1). Students are positioned as having to “acquire” new skills that are perceived to be relevant to interdisciplinarity through numerous new models of interdisciplinary teaching, learning and assessment (Dezure, 2017, p.566).
Despite an emphasis on the enjoyment and progress of students (for example, Lansiquot and Cunningham, 2016) in interdisciplinary learning, studies point to the challenges of teaching and learning in non-traditional disciplinary courses. Moreover, interdisciplinary learning is often associated with team-teaching as instructors are experts in a single disciplinary area, leading to problems of assessment and grading of students (Wolfe and Haynes, 2003), co-ordination and cost-effectiveness of the process (Duchovic, 2011), and team cohesion (Pociask et al., 2021). Lattuca et al. (2004) sum up the issues surrounding interdisciplinary education: empirical evidence of the positive effects of interdisciplinary education on (undergraduate) students’ learning is lacking, as is the theorising of interdisciplinary teaching and learning, inconsistent epistemologies of instructors, and issues of pedagogic strategies. In the context of doctoral education, these problems can be seen to persist. Interdisciplinary doctoral training is seen as risky for future academic careers (discussed in section 2.1), difficulties in establishing interdisciplinary curricula and teaching teams across the disciplines (Holley, 2009a), and effective doctoral supervision (Vanstone et al., 2013). Much of the research cited is relevant to the topic of the present study but highlights lacunae in the existing literature, the disparity and lack of connection between the relevant fields and the lack of empirical evidence originating in the specific social, cultural and economic context of the UK.

When students are discussed, they are often constructed along particular narratives that are over-reliant on concepts of human capital theory that
equate learning and earning (Brown et al., 2020, p.27). Brooks et al. (2022, ch.5) examined how these constructions are internalised and reinterpreted by students who come to equate education with credentialism, resulting in a fierce positional competition for qualifications and “credentials as ever-inflating ‘pieces of paper’” that add little or no value to individuals. In these narratives, education is a personal investment that will eventually pay for itself and is necessary for anyone wishing to fulfil their potential (Keeley, 2007), despite issues of over-qualification discussed in section 3.4.

At the international level, the USA have produced a high proportion of the existing studies, having experimented with interdisciplinary education through initiatives such as the National Science Foundation’s programme “Integrative Graduate Education, Research, and Training” (IGERT) discussed in Dooling et al. (2017), Pinter et al. (2013) and Graybill et al. (2006). These studies provide many insights into the successes and challenges of interdisciplinary education, but their origin limits their use. The American educational system is different from the UK and takes place in a different context; the IGERT programme took place nationwide across the USA, within very strictly specified guidelines, and in 2014, the NSF renamed the programme, removing interdisciplinarity as its main focus (Dooling et al., 2017, p.584). While UK policies push forward for the interdisciplinary training of an increasing number of doctoral students, these decisions are driven by the government’s agenda to ultimately deliver on their promises of technological progress for the welfare of the country and are based on an instrumental view of interdisciplinarity (discussed in section 3.1), problem-based, and
governed from outside the university and an “external corporate logic” (Hearn, 2003). This normative understanding of interdisciplinarity in policies penetrates universities, where it comes in contradiction with the longstanding norms of academia and academic practices.

### 2.3.3 Researching the doctorate through practices

As discussed in section 2.1, despite progressive changes, universities and doctorates have endured throughout the centuries and are still clearly recognisable social forms (Kemmis et al., 2014b, p.1). Theorising education as a social practice points to the role of human activity in ensuring the relative stability of social forms and meanings (Schatzki, 2001a). This starting point has been the precursor for numerous studies of social practices in the last few decades and has seen the flourishing of an array of social theories that take *practices* as their object of study (Rouse, 2001).

Before discussing practice theory as understood in this study, I firstly survey the existing literature on practices from the situated learning, sociomaterial and STS perspectives.

**Situated learning**

Perhaps the most enduring work on learning and practices has come from the work of Lave and Wenger on situated learning (Lave, 1990; 1993; Lave and Wenger, 1991; Wenger, 1998; Wenger and McDermott, 2002) and their concepts of communities of practice (CoPs) and legitimate peripheral participation. The primary unit of analysis in this work is the community of practice, and the focus is on learning as “doing”. Students are understood as
apprentices who start out as legitimate peripheral participants who will become full participants with experience. This seminal work was a real innovation in educational theories where learners were previously thought to learn by acquiring knowledge and highlighting that learning is a process of participation in activities, leading to membership in a community (Sfard, 1998). While much research continues to use CoPs as a concept, scholars have identified gaps and weaknesses in this approach, partly around fuzzy definitions of CoPs and their role. Hodkinson (2004) identifies a failure to address differences between newcomers and more experienced workers or members of the community, and issues of power, trust and pre-dispositions present difficulties in knowledge management (Roberts, 2006). For this study, I have considered and dismissed the concept of CoPs, despite the many insights it has engendered, favouring the opportunity to focus on practices, as discussed above. The concept of CoPs has been contested, and controversies over what constitutes a CoP are still ongoing (Nicolini et al., 2022). This thesis emphasises how interdisciplinarity and doctoral training are enacted by participants rather than on communities of practice as the focus for the research, as it can be misleading to think of interdisciplinarity as taking place in a community of practice that already shares the same interests and goals.

**Sociomaterial perspectives**

The issue of learning in the workplace has produced a rich body of literature on learning practices, especially by Fenwick and co-authors (Fenwick, 2013; Fenwick and Dahlgren, 2015; Fenwick and Doyle, 2016; Fenwick and
Edwards, 2012; Fenwick and Landri, 2012). This sociomaterial approach has been gaining momentum recently, advocating the use of STS as a sensitising device, with more or less success (Decuypere, 2018). As Decuypere (2018) and Fenwick and Landri (2012) argue, some of these studies merely “tell” that educational practices are sociomaterial, while they make a case for “showing” this by focussing on the relationality between individuals and objects in networks. Some theories that focus on sociomaterial practices are Cultural-Historical Activity Theory or CHAT (Holland and Lave, 2019) and Activity-Network Theory or ANT, originating from the STS field and works of Latour (1987) and Callon (1984) cited in Edwards and Fenwick (2010). CHAT and ANT were discounted for the present study primarily because of their inability to go beyond dualisms – culture/agency in CHAT and humans/objects in ANT. Social practice theories share some similarities in the way they conceptualise knowledge by connecting humans and objects but illuminate different facets regarding how knowledge travels and how practices are configured (Fenwick, 2010).

Science and Technology Studies

In the field of STS, scientific work has been observed and examined in all its aspects through the work of Latour and Woolgar (1986), Lynch (1994), and Knorr Cetina (1999), among others. Science studies have long identified the practices of scientists as important empirical sites for the understanding of science and scientific knowledge production (Amsterdamska, 2007; Soler et al., 2014, p.12; Sormani et al., 2017, p.113). Varied in their methodologies, these studies encompass ethnomethodology (Lynch, 1994), actor-network
theory (Latour, 1987), ethnography (Traweek, 1992), constructivist approaches (Knorr Cetina, 1981) and science-as-practice (Pickering, 1990; Pickering, 1992; 1993). Taken together as a body of literature, all the above approaches are concerned with the practices involved in scientific enquiry as being constituted and constitutive of communities, institutions, scientific identities, shared understandings, specific types of discourses, and fields of study. The STS field has mainly focussed on the work of established scientists and has been much more silent about doctoral education as a preparation for a scientific profession. Furthermore, educational research has been slow in taking up some of the insights provided by STS despite the richness of concepts and methods it provides (Gorur et al., 2019), although a special issue was published to reflect the value of marrying STS and educational studies (de Freitas et al., 2017).

Yet, the emphasis on scientific practices found throughout STS and the concepts that have originated from previous studies are crucial to the present study and provide a strong foundation for this thesis.

One such concept comes from the STS subfield of Studies of Expertise and Experience (SEE), driven by Collins and Evans (see Collins and Evans, 2002), who proposed a normative theory of expertise as a means to categorise the political legitimacy of multiple actors when members of the public are involved in research. This theory has been widely criticised for its weaknesses, and critiques have called for further articulations (Goddiksen, 2014; Jasanoff, 2003; Plaisance and Kennedy, 2014; Rip, 2003; Wynne,
2003), which the main authors provided subsequently (Collins and Evans, 2015; Collins et al., 2016). Despite its limitations and original application outside doctoral training, SEE has provided the concepts of “interactional” and “contributory” expertise, which have been found useful for thinking about how students learn and become experts across disciplines by allowing a focus on interactions between researchers (Gorman, 2002). Although expertise has been researched in the context of learning and the acquisition of knowledge (for example, Ericsson et al., 2018; Gobet, 2015) and in the importance of knowledge in society (Stehr and Grundman, 2011), the SEE concepts have not featured well in studies of interdisciplinarity, but has been found relevant in graduate education for collaborative research (Berardy et al., 2011), studies of integration and implementation (Bammer et al., 2020), and Collins et al. (2017) have identified the need to promote the interactional expertise of interdisciplinary students.

The most straightforward type of expertise is “contributory expertise” – the technical knowledge that competent professionals can contribute to a particular field of study (Collins and Evans, 2007, p.14; Collins et al., 2016). The concept of “interactional expertise” focusses on the importance of language (Collins, 2011) and posits that individuals can understand a practice through “linguistic socialisation alone” without actually practising (Collins, 2004). In other words, researchers from different disciplines working in teams require some interactional expertise to communicate effectively (Collins et al., 2006) without necessarily being able to contribute to other disciplines. Both types of expertise often rely on tacit knowledge that is
internalised and embodied in experts (Bammer et al., 2020). Tacit knowledge is understood as knowledge that cannot be made explicit (Collins, 2010, p.4) and is sometimes gained through interactions with other people (Collins, 2001) or through experience (Stehr and Grundman, 2011, p.17).

It appears there is little evidence that the issue of how students learn across disciplines has, so far as I know, been empirically researched using the concepts of expertise discussed above, but Ribeiro (2007) and Ribeiro and Lima (2015) have produced valuable research from their description of Japanese-Portuguese interpreters’ practices in the technology transfer from a steel company in Japan to one in Brazil. In their critique of interactional expertise (IE), Ribeiro and Lima (2015) explain in detail how SEE’s understanding of (pure) IE as linguistic socialisation alone is flawed in practice and that learning is dependent on experience and levels of “immersion”. Five types of immersion are identified: none, self-study, linguistic socialisation, physical contiguity and physical immersion ranging at one end from no learning experience to the other end as full involvement and hands-on practice. In a separate empirical work to investigate a pre-operational training programme for running a nickel industrial plant in Brazil, Ribeiro (2013) asserts that “experience alone leads to the acquisition of tacit knowledge, which in turn leads to expertise” and how learning opportunities provide different experiences, or types of immersion. For ease of presentation, the levels of immersion are replicated in figure 4:
The concept of expertise is, thus, the outcome of socialisation, which I will argue is central to understanding how students learn across disciplines and for the formation of interdisciplinary scholars (section 7.2.5).

This study contributes to the field of STS by following the tradition of examining scientific practices through practice theory and a strong connection with educational studies, which are explored in the following sections.

**2.3.4 Aboard the practice bandwagon**

Corradi *et al.* (2010) asserted that practice-based studies have started a “bandwagon” since the return of the practice concept in the last three decades. The term “practice” seems to be used for anything and everything in the existing research and abounds in studies of universities, scientific research and interdisciplinarity. For example, new practices of doctoral education are discussed by Baschung (2016), academic practice by Brew (2010) and interdisciplinary practice by McCallin (2001). This “appropriation”
of the practice term (Corradi et al., 2010) across the social sciences confuses the everyday notion of practice, as activities that humans carry out, with the long tradition of practice theory, which is concerned with the “socialness and sociality of practical being, action and interaction” (Grootenboer et al., 2017, p.2). In this practice theory perspective, education, learning, and researching are all academic and social practices and are the locus of research. The distinction between the everyday use of the word practice and its use in practice theory is crucial: the former provides no basis for describing what is actually “going on” when someone observes an activity, whereas the latter entails a specific ontology in which “organizations, power, science, education, and transportation are understood as constellations of, aspects of, or rooted in practices” (Schatzki, 2016, pp.28-29).

Since the literature focusses on different aspects of the PhD and interdisciplinarity from different epistemological and ontological positions, research and knowledge of doctoral students can be said to be partial and fragmented. This issue has led Lee and Boud (2008) to argue that insufficient conceptual attention has been paid to the doctorate as a set of interconnected practices, which is at the heart of the present study. Researching the practical enactment of doctoral education through practice theory provides a framework for a richer understanding of the concept of interdisciplinary research, allowing an in-depth examination of the many concerns identified to date around interdisciplinary doctoral training. With talks of interdisciplinarity increasing in academia and policy circles, it is now more important than ever to understand how they affect students, especially
as the “most misunderstood topic in education on all levels today” (Graff, 2016).

2.3.5 Practice theory in this study
Disciplines are social practices that are carried out by people in interactions and constitute social institutions (Schatzki, 2016, pp.28-29), so it is, therefore, difficult to talk of a “reality” to be studied but points to the fact that doctoral students become researchers through practices and in interaction with other individuals. Practices, in this sense, are the focus of the present study and provide the basis for understanding the features of the interdisciplinary characteristics of CDT-OPTIMA doctoral programme and how they are enacted by students. Policymaking is considered a practice too, which is imbued by the UK Government’s and UKRI’s understandings of why interdisciplinary research is perceived to be crucial in science and educational policies, providing the opportunity for comparing the policy rhetoric with the practices of CDT-OPTIMA’s students.

The interest in practice theory in education is relatively recent, but its origins can be traced back to scholars as diverse as Marx, Heidegger, Wittgenstein, Giddens and Bourdieu (Grootenboer et al., 2017, p.3), or even Goffman and Foucault (Jonas et al., 2017, p.xv). Such diverse origins and approaches signal divergent perspectives on practices and on how they can be conceptualised. Nevertheless, more recent work has aimed to formalise practice theory as an approach to demonstrate its increasing power and scope (Schatzki, 2001b). Since it is not possible to define a theory of practice
as a unified body of theories (Reckwitz, 2002), an alternative approach is to think of a family of theories, all concerned with praxeology, the theory of human action or practice (Rigg, 2014). It is also essential that scholars who use practice theory in their research clearly identify the conceptions and assumptions that underpin their work so as to build on and make contributions to the existing body of knowledge (Jarzabkowski et al., 2016).

Because of the diversity of perspectives involved in practice theory, the approach should be considered as a set of tools at the disposal of researchers (see section 2.3.6). The use of practice theory in this thesis is mainly predicated on the work of Kemmis et al. (2014b) and colleagues for their focus on education. The present study also draws on Schatzki (2001a) and a slimline version of his practice theory presented by Shove et al. (2012b) for their conceptualisation of practices.

Stephen Kemmis (Australia) and colleagues have greatly influenced the field of doctoral education through a focus on practices and have formed a network called “The ‘Pedagogy, Education & Praxis’ (PEP) Research Program”16 in collaboration with researchers from Australia, the Netherlands, Sweden, Norway, Finland, the United Kingdom, Columbia and the Caribbean (Edwards-Groves and Kemmis, 2016; Smith et al., 2010). The network

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provides a rich body of literature starting with four books: *Enabling Praxis: Challenges for Education* (Kemmis and Smith, 2008), *Critiquing praxis* (Ax and Ponte, 2008), *Nurturing praxis* (Rönnerman et al., 2008), and *Examining praxis* (Mattsson et al., 2008).

The book entitled *Practice Theory Perspectives on Pedagogy and Education: Praxis, Diversity and Contestation* notes the theory of education as practice has emerged since the turn of the century or so (Grootenboer et al., 2017, p.1). The authors build on their previous work in *Changing Practices, Changing Education* (Kemmis et al., 2014d), which consisted of empirical research in Australian schools. Kemmis and Mahon (2017, p.111) give some examples of arrangements that constrain or enable pedagogical practice in universities, some of which are laid out in figure 5 below:

<table>
<thead>
<tr>
<th>Cultural-discursive arrangements</th>
<th>Material-economic arrangements</th>
<th>Social-political arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared language (e.g., English)</td>
<td>Lecture theatres</td>
<td>Teacher-student relations</td>
</tr>
<tr>
<td>Disciplinary discourse</td>
<td>Office spaces</td>
<td>Team-teaching</td>
</tr>
<tr>
<td>Professional discourse</td>
<td>Timetables</td>
<td>Research collaborations</td>
</tr>
</tbody>
</table>

*Figure 5: Examples of university arrangements (Author’s own)*

These examples point to some difficulties encountered in universities in institutionalising interdisciplinary practices: research collaborations require material-economic arrangements such as time and space that are not always available within the wider disciplinary organisation of universities and rely on
a shared (interdisciplinary) language that is not the norm of traditional universities or departments. The three kinds of arrangements offered in the examples above are intertwined with dimensions of the social world: the social space (the resources that make possible the relationships between people), the semantic world (the resources that make communication possible), and the physical space-time (the resources that make possible the activities) (Kemmis et al., 2014d, p.32). The arrangements and their associated dimensions are what Kemmis and Mahon (2017, p.111) call the “practice architectures of university education”. Because practices are shaped by arrangements and dimensions, they interrelate and are, therefore, disrupted by a lack of resources in any element. Through their empirical research on university life in Australia in 1964, 1987 and 2015, Kemmis and Mahon (2017) clearly show that new arrangements enable new practices in universities while older arrangements are still present. Distant and recent arrangements can and do co-exist in the university, sometimes in contradictory ways, and form complex practice architectures. I have reproduced Kemmis’ theory of practice architectures in figure 6 to show how the many concepts are interrelated:
Despite numerous approaches to practice theory, scholars agree that practices are arrays of human activities, thus embodied and materially mediated (although in the posthuman tradition, practices also include nonhumans), based on shared skills or understandings and know-how (Schatzki, 2001b, pp.2-3). How these practices are organised is conceptualised differently by scholars, so the following points are offered in order to clarify my own conception of practice theory as used in the present study:

- In contrast to figure 6, Shove et al. (2012b, p.14) understand practices as comprising three elements: competence (know-how), materials (bodies and objects), and meaning (ideas, aspirations and symbolic

Figure 6: A theory of practice architectures
Reproduced from Kemmis

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[Last accessed 24/07/2022].
meanings). For Schatzki (2001a), practices consist of sayings and doings, with a strong emphasis on shared understanding or know-how. In this thesis, I conceptualise practices as made up of sayings, doings (as per Schatzki and Kemmis), and meanings (as per Shove). However, I acknowledge that sayings imply competence, doings imply materials, and meanings are social-political. Thus, interdisciplinary doctoral training requires discursive competence of, and within, disciplines, doings (student bodies, labs, writing, reading, and so on) and meanings that include what Schatzki et al. (2001, p.52) termed “practical intelligibility”. That is, to become competent researchers, students must be aware of what is acceptable and required for a PhD, for the peer community in which they work, and more generally, students require an understanding of what it is to be a researcher in a university. In my view, these are crucial elements of practical intelligibility for conceptualising the practices of doctoral training, with an acknowledgement that practices are interconnected and are themselves composed of multiple practices at times. For example, “researching” as a practice is made up of reading, working in a lab, writing, and interacting with equipment and other individuals. Further drilling-down into these practices is possible.

- For Schatzki (2001a, p.48), practices form nexuses of “bodily doings and sayings” that are organised (mentally) by understandings, rules, and what he calls a “teleoaffective structure” (Schatzki, 2001a, pp.50-53). The teleoaffective structure is described as acceptable or correct
ends or beliefs, or tasks to carry out these ends (ibid., p.53). Kemmis et al. (2013), influenced by Schatzki, conceptualise practices as organised through practice architectures. These practice architectures enable or constrain practices through three types of arrangements: cultural-discursive (language and discourses), material-economic (resources) and social-political (power and solidarity). Finally, for Shove et al. (2012b), practices are arranged in bundles and complexes when they are co-located or when they come to depend upon each other.

- While Schatzki (2019, pp.173-175) acknowledges relations between practices and arrangements, he cautions theorists not to overemphasise relationality as it can be dangerous to claim that relations alone compose social life. However, Shove et al. (2012b, p.14) is explicit about how competence (know-how), materials (bodies and objects), and meanings (ideas, aspirations and symbolic meanings) interrelate and this approach emphasises relations: between individuals (networks, p.66), between the elements of practice (performance, p.22), and between practices (p.81). Kemmis (figure 6) also privileges participants’ relatings.

- The elements of a practice are integrated when practices are enacted (Shove et al., 2012b, p.21) and represent what makes practice possible (Kemmis et al., 2013). I understand practices as happening in the moment; saying I can “do research” is thus not a practice, only a
discursive element that may contribute to the practice of doing research if integrated with other elements of doing and meaning.

- A further difference between Shove et al. and Schatzki is the performance of repeat practices. For Schatzki (2019, p.172), activities that compose practices can repeat, but each practice is an extension of a prior practice as it cannot return in a new moment. I believe the idea that practices can repeat is not a useful concept, given that each instance of a practice is a particular way of combining elements and can show variety between practitioners, albeit recognisable as a common experience. However, I side with Shove et al. (2012b, p.77) and their assertion that access to resources (elements) or the conditions in which practices are enacted (arrangements) are not equally or evenly distributed and can account for deviations among similar practices, resulting in the fact that some practices are more stable than others.

- Variations in elements or arrangements enable and constrain practices and pre-figure the necessary conditions for new practices to emerge. An example for the present study would be an acknowledgement that interdisciplinary research is underpinned by disciplinary knowledge. In this perspective, context is understood as arising from practices and not independently, and context can affect which practices can be carried out. When new practices are enacted, they influence the social, economic and political environment (context) in which they are enacted. Thus, practices construct what is
acceptable for a community of peers and how practitioners make sense of and act in the world. For example, interdisciplinary practices can (re-)define a field or lead to the birth of an interdiscipline, thereby creating a specific understanding of the field and its objects of study (for an example, see Schyfter, 2013).

- Practices are involved in the maintenance and reproduction of social structures and institutions and allow individuals to recognise them as such. A university, independently of the multitude of different practices present at the institution, is thus recognised as an institution of higher education through practices such as research and teaching. The introduction of interdisciplinary practices both reproduces the idea of what a university does and also gives rise to variety in universities, allowing some scholars to express the concept of the entrepreneurial university (Jessop, 2017) with reference to their economic and social missions.

- As Grootenboer et al. (2017) argue, “practices are never just practices.” Each practitioner brings their own biography when participating in practices which may bring tension and struggles. Practices relate to, depend on or are co-located with other practices and form complexes (Shove et al., 2012b, p.87). In the present study, I understand interdisciplinary practices as related to, dependent on and co-located with disciplinary practices.

- Practices are enacted by students with different degrees of competencies and rely on certain components or elements, which are
all highly variable depending on the space and time in which they are produced. Practices are not visible before they are enacted and can therefore be said to be unpredictable, complex and continually changing and evolving.

- Sometimes, practices can come in direct tension or competition with other sets of practices (Shove et al., 2012b). In terms of researching at the doctoral level, this is probably most commonly experienced between reading and writing. Both activities are required – they are dependent on each other – but they also need to be arranged so that one does not prevent the other.

- Practitioners, as carriers of practices, may belong to several communities (or disciplines) and may voluntarily or involuntarily disrupt (either negatively or positively) the existing practices of one or more communities to which they belong. As students move between disciplines, there is an opportunity for them to carry some disciplinary practices to another domain. It should be noted, though, that the concept of practical intelligibility involves the acceptance of (new) practices by the community to which students belong if it is to be understood as competence.

- Practices anchor and provide a structure for their enactment because they are patterned and meaningful (Swidler, 2001, p.88). For example, Schönbauer (2017) was able to show how scientific meetings constitute a practice that also orders what scientists do, for example, in seminars, how it is done, and how biologists related to each other
“within and through practice”. It is in this sense that social practices can become visible to the observer. In the following section, I examine practice theory and its uses in past research endeavours.

**Disciplines and practice theory**

As the site where doctoral training practices happen, universities are a useful starting point for thinking about doctoral training in terms of practices. And as part of the universities’ social world, doctoral education can be thought of as a microcosm, which is itself subjected to broader social forces (Hopwood, 2018, p.13). The seminal work of Becher and Trowler (Becher, 1989; Becher and Trowler, 2001; Trowler, 2014a; Trowler et al., 2012) identified that disciplines condition the behaviours and values of academics and thus perform a social function. Through interviews with academics across institutions and disciplines in the USA and the UK, the first two editions of *Academic Tribes and Territories* (1989, 2001) provided, for the first time, an in-depth account of knowledge structures and research cultures in universities, marking a rise of scholarly interest in academic work, outside historians and STS fields (Messer-Davidow, 1992). The third book (Trowler et al., 2012) reviewed the whole thesis and introduced a social practice theory as a completely new perspective. The importance of academic disciplines in research and education has been discussed in section 2.1.3, noting the difficulty in arriving at a definition. Although disciplines are often viewed as static entities from afar, the thesis of strictly bounded and easily identifiable
Disciplines does not hold any longer (section 2.2). However, in the third book, Trowler et al. (2012, p.9) articulates a definition of disciplines from a practice theoretical perspective that is re-worked in a reflective paper (Trowler, 2014a, pp.24-25) and used in this thesis (my emphasis):

Disciplines are reservoirs of ways of knowing which, in dynamic combination with other structural phenomena, can condition behavioural practices, sets of discourses, ways of thinking, procedures, emotional responses and motivations. Together this constellation of factors results in structured dispositions for disciplinary practitioners who, in conjunction with external forces, reshape them in different practice clusters into localised repertoires. While alternative recurrent practices may be in competition within a single discipline, there is common background knowledge about key figures, conflicts and achievements. Disciplines take organisational form, have internal hierarchies and bestow power differentially, conferring advantage and disadvantage.

This definition is favoured for the present study as it makes clear disciplines are dynamic and evolving entities that are enacted locally. They can be reshaped through the practices of researchers and can co-exist or come into competition with other forms of practices. Yet, disciplines are identifiable because they share repertoires and common backgrounds (ways of knowing). I would also add the principle of practical intelligibility found in Schatzki (2001a, p.52), which points to the need for a practice to be accepted and recognised as such by its practitioners; rather than an “anything goes” approach. A practice theory perspective does not take disciplines or researchers as determinants of one another: disciplines can condition behaviours, and researchers can reshape disciplines. This is an example of the ontology of practice theory.
described by Schatzki (2016), which does away with dualisms such as micro/macro levels, structure/agency, or social/material, but takes into account the mutual constitution of these dualisms (Feldman and Worline, 2016, p.2; Nicolini, 2013) and shows how they are clusters of relations among practices and arrangements.

2.3.6 Critique of research design

Practice theory has been criticised for not representing a theory or school of thought and for being scattered (Schmidt, 2018). Viewed in this way, I would argue this is not an uncommon characteristic of various research tools and fields at the disposal of researchers. For example, STS has been judged for lacking a methodology and for “cherry-picking” methods relevant to the study at hand (Fuller, 2006, cited in Decuypere, 2018). Similarly, the field of sociology of education is described by Apple et al. (2010, p.1) as “a diverse, messy, dynamic, somewhat elusive and invariably disputatious field of work.” However, from a practical perspective, the variety of tools offered by STS and practice theory allows for creativity in trying to bring fresh perspectives to issues and avoiding the explosion of publications that have nothing new to say (Alvesson, 2013b) and using theories as “straight-jackets” (Decuypere, 2018). The insights provided from these new perspectives can then be evaluated and discussed further, thereby contributing to the advancement of knowledge in the field and keeping a vibrant and dynamic research community.
By saying that practices are locally enacted, evolving and at times unpredictable, and that realities are multiple, it is clear that this study does not propose a "one world" view (Law, 2015) of interdisciplinary doctoral training, nor does it subscribe to a one reality world. Individuals, institutions and policies are involved in constructing interdisciplinarity, which should remain understood as a heterogeneous concept. As such, findings may not easily translate across time and locations, but as governments and universities are engaged in attempts to stimulate interdisciplinary research and training, they may face similar challenges. Similarities across nations and institutions should not be taken for granted and are also accompanied by differences. This is perhaps only implicit in the accounts given in this thesis but is evidenced by the breadth of literature relied upon. Thus, this study is well suited to generate insights and methods for further research and to raise questions about different forms of interdisciplinarity and the future of students in many contexts.

The implications of applying practice theory to interdisciplinary doctoral training are, like in many qualitative studies, found in the researcher’s choices on where to focus their attention and their methodological choices (e.g. Ritchie et al., 2014). As a finite piece of research, a thesis cannot take into consideration all the elements of a “practice of doctoral training” and necessarily focusses on some aspects rather than others. “Education for the good of those involved” as advanced by Kemmis et al. (2014d, p.24), is one example of the many facets this thesis does not discuss, but that is closely aligned with my own thinking. In my view, this type of education, and the
practices it seeks to disseminate, would be underpinned by understandings of major issues that currently pre-occupy the world and in which researchers could play a crucial role. One of these issues is the UN’s Sustainable Development Goals (SDGs)\(^\text{18}\) and the need to address the world’s complex problems of climate change, poverty, education and health. While UKRI recognises the crucial role of UK research in finding solutions towards those sustainable goals\(^\text{19}\), it is not clear how doctoral programmes (and education more generally) contribute to the development of researchers who situate their work towards achieving the SDGs. There is obviously much research undertaken in the UK that is relevant to achieving these goals but little evidence that educational changes seek to foster developments in this area. During this research, I observed that CDT-OPTIMA students are sometimes steered towards thinking about innovations in terms of portability to low and middle-income countries and problems of affordability. Future research could examine in detail the ethical and moral dimensions of doctoral education, which remained outside the scope of the present study.

Studies of practices concentrate on apparent, manifest and observable activities and everyday interactions (Schmidt, 2017), posing challenges as to what should be observed and what is available to the researcher. It is both impossible and undesirable to record everything that happens in the field because of the infinite richness of social scenes and the amount of data this


\(^{19}\) UCL, 2019, Ensuring research is effectively at the heart of achieving the UN’s sustainable development goals. Online https://www.ucl.ac.uk/steapp/news/2019/jul/ensuring-research-effectively-heart-achieving-uns-sustainable-development-goals [Last accessed 30/07/2022].
would produce (Ritchie et al., 2014, p.253). These issues affect all studies that are in the form of ethnography with observation as a method to investigate the *here and now* (Miettinen et al., 2009), and much advice has been offered in academic books (Patton, 2015; Ritchie et al., 2014; Silverman, 2019). Accordingly, the present study focussed on the troublesome practices reported by the participants during fieldwork.

Section 2.1 of this chapter presented the background for the study, focussing on the historical disciplinary organisation of universities and the doctorate and how students are socialised in a discipline. Definitions of interdisciplinarity, its relationships to other modes of knowledge production and related terms were discussed in section 2.2. Practice theory and the extant literature were examined in section 2.3. to provide the theoretical framework for the present study. Chapter 3 will continue with further background, in this instance focussing on the politics and policies at play in the UK, providing some possible explanations as to why interdisciplinarity is seen as an essential tool for the country’s welfare.
Chapter 3 Policies and politics of knowledge production

“Education is the passport to the future, for tomorrow belongs to those who prepare for it today.”
(Malcolm X, cited in Arvanitakis and Hornsby, 2016, p.9)

Implicit in the practices of universities is a concern with the long-term future. As sites of production and regulation of knowledge, universities are institutions of the future (Facer and Wei, 2021, p.192). Examples of this future orientation are the training of future generations of scientists and intellectuals (Bogle et al., 2011), the preservation of cultural and natural heritage (Harrison, 2021, p.35), and the production of new knowledge to solve complex societal problems, such as climate change (Rickards et al., 2014). The idea that education and the future are tightly interconnected, as typified in the above quote by Malcolm X, is an enduring and alluring thought as it links statements about expectations with current practices. From a sociology of expectation perspective (van Lente, 2012), such statements offer a valuable resource to guide and convince different stakeholders. In particular, it offers the vision of education as delivering a more certain future, which therefore merits investment and the coordination of current practices for a shared vision of the future.

At the same time, a preoccupation with the future of universities in Britain and elsewhere is decades old, as attested by the Report on Universities Development 1944 (Pacey, 1944) and, more generally, by the repetitive debates concerning the role of universities in society since the early
nineteenth century (see Collini, 2012, p.39). Despite being funded by the government, post-World War II universities maintained their relative autonomy from state interference and their development was assured by the academic community until the creation of the Funding Councils in 1989 (Filippakou and Tapper, 2019, p.8; Shattock, 2008). This most significant change in UK Higher Education has had lasting implications for the relationship between UK universities, funding councils and the government (Filippakou et al., 2010) and laid the ground for endless debates concerning the mode of governance of UK universities and their level of autonomy (for example, Dobbins and Knill, 2014, pp.110-111).

Amid these complex tensions and disagreements about who is really governing UK higher education, universities have been made central to the knowledge society (discussed further in section 3.5) since the 1980s (Tapper, 2007, p.225), especially for the perceived role of scientific knowledge in the pursuit of economic productivity. This chapter examines the UK political strategies employed to steer the work of universities while seeking to solve Cardwell’s riddle (the perceived need for the growth of innovation), the role of CDTs in promoting interdisciplinary doctoral training and further efforts to align such doctoral programmes with the political visions for a better future. The last two sections of this chapter discuss the politicisation of science (section 3.6) and the political economy of knowledge (section 3.7) as some of the consequences of the UK policies and politics of knowledge production. Firstly, though, the discussion starts with an explanation of the different types of knowledge in policy to differentiate between research-led knowledge
(basic research) and policy-led knowledge (research that aims to provide solutions to current problems).

### 3.1 Types of knowledge in policy

From the UK research councils and policy perspectives, research is usually divided into “pure, basic or fundamental” and “applied or practical” types (Bentley *et al.*, 2015; Calvert, 2006). Basic research is generally understood as the production of knowledge for its own sake, while applied (also strategic) research usually seeks solutions to problems (Salter and Martin, 2001). The Frascati (OECD, 2015, p.50) guidelines and indicators for Science, Technology and Innovation recognise basic research and divide practical research further into two categories: applied research and experimental development. According to Frascati, applied research gives operational form to ideas (from basic research), and experimental development produces new products or processes.

In other words, basic research is associated with Mode 1 of knowledge production and applied research with Mode 2 (Bentley *et al.*, 2015), as discussed in section 2.2.3. From an economic perspective, applied research is seen as superior because the research outcomes usually justify the investment in the form of new products or services. In contrast, basic research’s return on investment involves a longer and more uncertain time lag (Salter and Martin, 2001). From an academic perspective, the differences between types of research are not as clear-cut and continue to spark debates concerning the future of academic research. Some scholars like Nowotny *et
al. (2003, pp.181-2) deplore the steering of research priorities through funding systems and argue that pure research “is now a minority preoccupation – even in universities.” However, Bentley et al. (2015) mapped the presence of basic research in universities across fifteen countries and found a much more nuanced picture. They claim that, despite variations across countries and disciplines, basic research continues to define academic work.

Similarly, in a survey in Norway, Gulbrandsen and Kyvik (2010) found the steering of research priorities towards applied research weakly founded in empirical studies. Salter and Martin (2001) reviewed the literature on the benefits of basic research and argued that returns on investments alone are a poor representation and found six major contributions of basic research to economic growth: increasing the stock of useful knowledge, training skilled graduates; creating new scientific instrumentation and methodologies; forming networks and stimulating social interaction; increasing the capacity for scientific and technological problem-solving; and creating new firms. Petit (2004) also argues in favour of basic science (what he calls “fundamental science”) for a better structural link between science and society, as science cannot be reduced to that which society expects. Not all researchers agree with this view, despite confirming the importance of basic research. For example, Bowen et al. (2021) reflect on their experiences of health research partnerships during COVID and argue: most important research issues require interdisciplinary research; thus, applied solutions must receive greater support.
Whether the UK Government favours basic or applied research can be examined through official statistical data provided by the Office for National Statistics (ONS) and their dataset on research and development expenditure by the UK Government\(^2\) for the years 2009 to 2020.

The government’s expenditure on research and development, as reported by the ONS, shows a further split in basic research as per the Frascati manual’s (OECD, 2015, pp.50-51) breakdown: basic-pure is the only type of research activity without “particular application in view” while basic-oriented is expected to form the basis of solutions to problems. Expenditure on all types of research has grown over the period, but experimental development work has shown a significant increase since 2017. Aggregating the data into basic and applied research reveals a different trend and shows the UK Government expenditure on research has increased faster for applied research than basic research. If basic-pure research is compared to all other types of research that can be called instrumental (including basic-oriented), then it forms only a small part of all UK Government expenditure on research activities. In percentage terms, the increases shown in the figures for UK Government expenditure between 2009 and 2020 on each type of research are as follows: basic-pure 59%, basic-oriented 24%, applied strategic 71%, applied-specific 113% and experimental development 3171%.

\(^2\) ONS dataset showing research and development expenditure by the UK government (at current prices) can be found online Research and development expenditure by the UK government - Office for National Statistics (ons.gov.uk) [Last accessed 28/06/2022].
While researchers in universities may fear that governments are steering research towards applicability, the literature discussed in this section shows basic research is still the dominant mode of academic work, despite government funding data. This points again to the fact that research activity types are not easily identifiable in academic practice and supports the work of Bentley et al. (2015), namely that while there seems to be a policy push for applied research, core academic values are not changing. The figures may also reflect the general view that interdisciplinary research is mostly concerned with finding solutions to societal problems, but this may partially be due to policymaking activities rather than an indication of a change in academic practices.

An orientation from basic to applied knowledge in policy would indicate a transition toward the “instrumentality” of knowledge (knowledge directed at technological progress), and thus, a type of knowledge production that effects changes to the “social contract of science”; an STS concept used to denote relationships between science and society (Hessels et al., 2009; Krishna, 2014). The policy rhetoric around the applicability of science for society is often presented, in the academic literature, as in direct opposition to the core traditional academic values of autonomy and disinterestedness (Ziman, 2000a; b), which some scholars see as an issue of government interference in academia (see section 3.6). However, caution should be exercised when defining knowledge as instrumental. Since much of UK research is financially supported by the government and other funding
bodies, it is already imbued with the interests of stakeholders, thus, as Ziman (1996) noted, even basic research serves political interests.

Linked to this discussion is the concept of “curiosity”, which has long been associated with scientific research and education, at least in policy circles. For example, it is thought that maintaining pupils’ curiosity is an essential ingredient in school science teaching (Ofsted, 2013) and refers to the assumption that curiosity is an individual trait of scientists (Couto, 2018). Psychological studies maintain that children’s scientific thinking is driven by curiosity or a desire to see information and should therefore be promoted for science learning (Jirout, 2020). Yet, the term curiosity suggests a specific type of research and, therefore, a quality of the research as a product or process and is generally associated with pure (or curiosity-driven, blue sky, uncommitted, oriented basic or fundamental, science-driven, and frontier) research (Nowotny, 2008, p.72). The image of the curiosity-driven researcher is a powerful instrument in policy to promote the idea of the autonomous scientist, free to pursue their own interests and research. However, efforts to drive knowledge production in line with market and societal orientations can be understood as the domestication of curiosity (Nowotny, 2008, p.24), that is, itself, steered towards national priorities and Agar (2017) has previously noted that the concept of curiosity is a rhetorical tool which is deployed for specific purposes in science and education policy. As will be discussed in section 6.3, the concept of curiosity is increasingly used in the political rhetoric of interdisciplinarity, where it becomes linked with the idea of creativity, thus making it an attractive proposition for students.
3.2 Cardwell’s riddle
The expectation that science will lead to technology is commonplace worldwide as nations seek to improve their standards of life and economic advancement (Taylor, 2016, pp.40-41). Many countries see a lack of innovation as a severe detrimental issue that needs to be addressed through countless policies and strategies in the name of an "innovation imperative", not only for their economic productivity but also as a resource for international competitiveness (Pfotenhauer et al., 2019). The idea of international competition is reinforced in Europe, for example, by the Lisbon Strategy of the European Council (2000) and its aim “to make Europe by 2010 the most competitive and dynamic knowledge-based economy in the world”. Similarly, the UK Government has pursued policies seeking a competitive advantage for a Global Britain as a science superpower (UK Government, 2021a, p.6). For example, in CDT-OPTIMA’s biomedicine field, the perennial question has been how to catalyse scientific research to deliver rapid and revolutionary advances in medicine and healthcare? (Aarden et al., 2021). The puzzle over how countries become leaders in the creation and production of Science and Technology is described by Taylor (2016, p.3) as Cardwell’s Law, by reference to Donald Cardwell, a 1970’s British historian who catalogued past development of Western science and technology. I employ Cardwell’s riddle here as a concept for how Britain finds itself in and navigates the race to be a world leader in new healthcare treatments and technologies (UK Government, 2021a).
Renowned for its highly respected research universities and high scientific outputs, the UK is relatively ranked poorly as an innovating nation (Taylor, 2016, p.96) and has been investing heavily in its innovation ecosystem and research and development activities (BEIS, 2021, p.17). For this ecosystem to thrive, it requires a workforce and, hence, the training of researchers in strategic areas of science, for example, biomedical and clinical research. These fields are known for their failure to translate new knowledge into innovation, and this is what is termed “the valley of death” with an estimated 85% waste of all research funding (Weggemans et al., 2018), mainly due to a lack of investment in the intermediate stage of the projects (Auerswald and Branscomb, 2003; Beard et al., 2009). When it happens, the translation of research evidence to clinical practice is thought to involve a time lag of seventeen years, implying high costs and delays for patients (Morris et al., 2011). Typically, these issues pose governments and funders a major problem for investments in science and how best to utilise budgets given such a long delay before economic returns (Grant and Buxton, 2018). Cardwell’s riddle is therefore not solved by translational science but there is ongoing work to increase value and reduce waste in biomedical research (Macleod et al., 2014).

Translational science (or medicine, or research) has become an all-encompassing term in research policy to bridge a so-called “gap” between the knowledge produced by the life sciences and the use of this knowledge – in the form of new services, products or techniques – in the clinical field (van der Laan and Boenink, 2015). This specific type of science is often commonly
known as “bench to bedside”: the expectation that knowledge produced at the scientific laboratory bench can be used to treat patients (Callard et al., 2012). Translational science necessitates teams of researchers to work collaboratively and is, therefore, mostly always referred to as interdisciplinary, though not all interdisciplinary research is collaborative nor applied (Martin and Pfirman, 2017, p.587).

One of the essential components of translational research is a culture of collaboration (MRC, 2018, pp.4-5; Sixsmith et al., 2021), for which the academic sector is not adapted. The MRC’s evaluation report on translational science 2008-2018 (MRC, 2018) states that barriers to translational science are a lack of team science, the reward and promotion structures of academia, and the lack of communication between academia and policymakers. Nevertheless, collaborative work and interdisciplinarity (or even transdisciplinarity) are often conflated in the literature (for example, Andersen, 2016; Baum and Bartkowski, 2020; Holt, 2013) and refer to teams of scientists from different disciplines collaborating on a project. Therefore, translational science depends heavily on interdisciplinary collaborative work (Guerrero et al., 2017). It should be reiterated that not all interdisciplinary research is collaborative or applied (Martin and Pfirman, 2017, p.587).

3.3 Research training in a Centre for Doctoral Training
UK universities are social institutions that produce both knowledge and future scientists and have been called in policies, “powerhouses of intellectual and social capital” (Jo Johnson in BIS, 2016, p.5) - pointing to the importance of
higher education and learning processes in sustaining the scientific knowledge base of society and ensure its continuing advancement. In a bid to solve Cardwell’s riddle (discussed in section 3.2), the UK Government identified the need to train a new generation of scientists who would become the leaders and innovators of the future: skilled individuals who would be able to translate academic knowledge into new services or products in specific areas of strategic research and skills priorities. Funding calls were issued to allocate investments in various doctoral training schemes with highly defined characteristics, such as the Centres for Doctoral Training, Doctoral Training Partnerships and Industrial CASE studentships\textsuperscript{21}. The UK devolved nations (England, Scotland, Wales and Northern Ireland) operate different higher education and funding systems (Brooks \textit{et al.}, 2022, pp.16-17) but also share government funding through the UK research funding body UK Research and Innovation (UKRI). UKRI comprises eight research councils that operate across all four nations, established along research areas and representing different academic disciplines as implied in their titles. The councils are the Arts and Humanities Research Council (AHRC), Biotechnology and Biological Science Research Council (BBSRC), Economic and Social Research Council (ESRC), Engineering and Physical Sciences Research Council (EPSRC), Innovate UK, Medical Research Council (MRC), Natural Environment Research Council (NERC), and Science and Technology Facilities Council (STFC). CDT-OPTIMA, the interdisciplinary doctoral

\textsuperscript{21} UKRI, Types of training, online at https://www.ukri.org/what-we-offer/developing-people-and-skills/stfc/training/types-of-training/ [Last accessed 15/12/2022].
training centre in optical imaging for healthcare, which was the site for this study, was co-funded by EPSRC and MRC.

EPSRC’s vision for the type of training to be delivered by its CDTs in technologies of health and care\(^{22}\) is detailed and prescriptive and as follows (p.1):

- Equip […] scientists with the skills, knowledge and confidence to tackle current and future challenges.
- Ensure advances in research in many areas of fundamental science and engineering, as well as providing future leaders in key areas for the UK economy.
- Provide a supportive and exciting environment for students, creating new working cultures, building relationships between teams in universities and forging lasting links with industry.

This vision was based on previously identified priority areas to avoid systemic skills shortages, points to the need to be highly interdisciplinary and the 2013 funding call stated the CDTs were expected to include some of the following purposes: development of new sets of skills or of identified future core skills, strong user pull, translational challenges, or to encourage culture change\(^{23}\).

An EPSRC mid-term review of their CDTs (funded in 2013/14, which included CDT-OPTIMA) was released in 2017, claiming the CDTs were “providing high-quality training which was setting the gold standard for cohort-based


doctrinal training in the UK”²⁴. However, following a request under the Freedom of Information Act (2000) to access the mid-term review data, the UKRI Observatory²⁵ produced its own analysis and concluded EPSRC’s claims were hard to justify²⁶, pointing out specifically that “this demonstrates a lack of respect for the interests of students”. The UKRI Observatory analysis revealed over 60% of the CDTs were rated lower than “good”, and the funding of CDTs was directed towards highly esteemed universities, which had, in fact, performed poorly. Some universities were relocating their internal funds to co-fund the CDTs instead of attracting matching funds from industry partners. EPSRC launched a new call for CDTs in 2017/18, and the UKRI Observatory offered a preliminary analysis, again raising questions regarding the sustainability of these centres and the quality of the training²⁷. The analysis pointed out that only a small number of the originally funded CDTs were renewed (37 out of 115) and that if EPSRCs figures were correct, the cost of a CDT studentship would be three times the cost of a traditional three-year studentship, an “extravagant amount to spend per student.” CDT-OPTIMA was one of the CDTs that did not manage to renew their funding despite being rated good/satisfactory in the 2017/18 mid-term review. I should note I have been unable to find more information on UKRI

²⁵ UKRI Observatory. Finding out about the CDT program through Freedom of Information. Online. https://ukri.info/part_2_cdt_investigation.html [Last accessed 06/07/2022].
²⁶ UKRI Observatory. Is the CDT scheme working? Online. https://ukri.info/part_1_cdt_investigation.html [Last accessed 06/07/2022].
Observatory, and the website has not published any further material since their 2019 preliminary analysis, despite claims a more detailed analysis was forthcoming. However, it is clear that doctoral training centres had been raising significant issues, as was the case with ESRC’s 2011/12 centres²⁸.

CDTs, therefore, have been shown to offer less than optimal models for the training of postgraduate students and have been accompanied by multiple reviews and changes in the delivery of the PhD more generally (section 3.4). Moreover, many challenges and issues related to the field of medical imaging technology were scoped and reported on by the EPSRC and MRC working in March 2012 (EPSRC and MRC, 2012), further highlighting how the UK could improve its international standing in this area. While the UK Government boasts impressive results²⁹ in terms of medical technologies and innovations, the influence of interdisciplinary research and translational science training on students is the concern addressed by this study. The next section examines some notable developments in postgraduate education in the UK through a detailed discussion of several reviews of the doctorate over the recent past.

²⁸ Times Higher Education. Holly Else, 05 February 2015. ‘Significant issues’ raised by review of PhD training centres. Online. [Last accessed 06/07/2022].
3.4 Reviewing doctoral education

The UK Government’s scrutiny of doctoral education jumpstarted several decades ago with the publication of the review of Lord Robbins (1963, pp.275-276), who recommended the economic use of public resources and long-term expansion of universities to accommodate the large incoming cohorts of students born immediately after World War II. This review was followed by the 1982 Swinnerton-Dyer Report of the Working Party on Postgraduate Education, which focussed on future workforce needs rather than training quality and issues (Walford, 1983). The gap of nearly twenty years between these two reviews, which may indicate a lack of concern for postgraduate education in government policy, was followed by six significant policy statements and the next comprehensive review, known as the 1996 Harris report of postgraduate education (Burgess et al., 1998; Hogan, 1997; Pole, 1998). The Harris report is relevant to the present study as it focussed on joint supervision for postgraduate students, which Pole (1998) showed to be effective for the support of students, depending on the “number of people involved in the joint supervision arrangement, their status, their knowledge and skills which they bring to the relationship and the availability of members of the team to the doctoral students.” CDT-OPTIMA students typically have at least two supervisors, one from the University of Edinburgh, one from the University of Strathclyde.

Fast-forwarding to the last three years, at least four significant reviews and reports reflect the growing interest in postgraduate education, from the government and other organisations and the importance doctoral education
has acquired in the country’s research and development ecosystem. These reviews followed Sam Gyimah’s\(^{30}\) (minister for higher education at the time) pledge to be “a minister for students – placing a laser-like focus on students.” The list of most recent reviews and reports is summarised in figure 7.

<table>
<thead>
<tr>
<th>Author</th>
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<tr>
<td>EPSRC (2021)</td>
<td>Review of EPSRC-funded Doctoral Education</td>
<td>Funding council (EPSRC)</td>
</tr>
<tr>
<td>Tazzyman et al. (2021)</td>
<td>Review of the PhD in Social Sciences</td>
<td>Funding council (ESRC)</td>
</tr>
<tr>
<td>Smith McGloin and Wynne (2022)</td>
<td>Structures and strategies in doctoral education in the UK and Ireland</td>
<td>UK Council for Graduate Education</td>
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*Figure 7: Recent reviews into university (graduate) education*

The Augar (2019) review shows a strong concern for graduate skills and seeks a “system [that] genuinely works for everyone.” (p.27). The report identified skills shortages, mismatches (p.25) and an over-qualification at the graduate level (p.31), meaning England oversupplies graduates compared to demand. Technological productivity and economic growth visions have led the UK, and other knowledge-based economies, to associate investments in education with an increasing need for a highly skilled workforce to fulfil employers’ demand (Lloyd and Payne, 2016, ch.1). Over-qualification of a

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nation’s workforce is not easily measured but reports are consistently finding that the expansion of the UK higher education sector has seen “graduate supply increase faster than the number of high-skilled jobs”, leading not only to over-qualification of the workforce but also to under-utilisation of skills (CIPD, 2015; Lloyd and Payne, 2016, p.25), leading to graduate “crowding” (Elias and Purcell, 2013). The CIPD (2017) report dispelled the myth of the graduate employment gap, concluding high-skilled jobs failed to keep pace with the increase in the number of graduates who would therefore be forced to fill non-graduate jobs. Yet, the political agenda to train a highly skilled workforce for the nation's future persists (UKRI, 2022). The present research seeks to examine the government’s turn to interdisciplinary doctoral training in the context of producing a highly skilled workforce for innovation, as well as the students’ motivations for undertaking this type of training.

The EPSRC (2021) review of doctoral education is set in the context of the UK’s need to be competitive and productive and for a workforce with the right skills which will be highly employable both in industry and academia (p.3). In order for the UK to become a superpower, skills need to increase, and so do numbers of PhD students, especially to grow Science, Technology, Engineering and Mathematics (STEM) capabilities, which are highly valued by industry (p.5). EPSRC notes under recent government strategies (p.24) that “productivity growth [historically] can be attributed to higher skilled cohorts.” EPSRC graduates are said to make an important contribution to new knowledge and publications and are highly employable due to their wide range of transferrable skills (p.55). Transferrable skills valuable to
organisations and common in doctoral graduates are listed as independence and resilience, analytical skills, communication skills and team working (p.48). While skills development was always a part of the doctorate, they were only implicitly implied in the fact that students had contributed to knowledge and possessed the skills necessary to undertake research (Denicolo and Reeves, 2014). With a majority of doctoral students now choosing career paths outside academia, it has been found that research skills are not preparation for jobs that allow employees to work efficiently immediately (Phillips, 2010), hence the need for universities to develop students’ transferrable skills. This training is not considered necessary for research and is a hotly contested and criticised topic in universities (Gilbert et al., 2004). This thesis will examine CDT-OPTIMA students' views on their mandatory three-month placements and whether they felt their PhD programme had helped them during this activity (and if so, how).

The ESRC review of the social science PhD (Tazzyman et al., 2021) similarly asks which skills would prepare students for careers in academia and beyond (p.6). This report focuses on core research skills such as quantitative training but also reiterates the imperative for students to develop transferable employability skills, noting “the differences in the transferable skillset required for academic and non-academic careers are minimal.” (p.8). ESRC calls for more opportunities for students to undertake collaborative and interdisciplinary work and an extension of the PhD funding to four years instead of the three years currently funded programmes (p.7). As per the previous reviews noted above, ESRC wants to encourage links with
businesses and other partners in recognition of the range of career paths students progress to (p.16). The report shows concerns for the employability of social sciences graduates who are not sought after in any sector, apart from a small number employed by the NHS.

In contrast to the EPSRC review, ESRC notes that employees do not expect work-ready graduates (p.25). However, non-academic employers are reported to have identified skills gaps in general employability skills of graduates (p.26) and, similarly to the EPSRC review, raises employability issues. Graduate employability is a major concern of universities and employers alike, and a source of tension as to who is responsible for readying the workforce (Herbert et al., 2020), especially due to inconsistencies in their differing understandings of graduates “work-readiness” (Blackmore et al., 2015, p.7). Peeters et al. (2017) developed a conceptual framework for measuring employability, which they define as competencies to gain and maintain a job, based on the notion of “capital” as developed by Bourdieu (for a recent account, see Bourdieu, 2008). While Peeters et al. (2017) note the effects of class and social inequalities, the use of “employability capital” tends to lead to studies that are based on competencies that individuals are thought to possess rather than how people actually use them (also see discussion in Römgens et al., 2020). Such research often laments that despite many efforts by universities to promote social mobility, higher education exacerbates the problem, and disadvantaged students continue to experience problems entering the labour market (Parutis and Howson, 2020). While universities have a responsibility
to support disadvantaged students to fulfil their potential, there is no guarantee that employability capital will lead to employment because of structural factors such as ethnicity, gender and age (Lloyd and Payne, 2016, p.19). Healy et al. (2020) argued their research is the first to analyse graduate employability and career development research together and commented that while employment is an outcome, employability is an antecedent. For the purposes of this study, I understand this to mean that developing students’ employability capital cannot guarantee future employment; likewise, developing students’ capacities for entrepreneurship and innovation does not dictate the future career paths of students. Graduate employability is becoming critical to universities and how they market themselves to prospective students. For instance, Pizarro Milian and Missaghian (2019) analysed over 200 Canadian interdisciplinary programmes’ contents and how they promote themselves. They found the presence of a labour market logic where interdisciplinary programmes promise the best preparation for future jobs as a “sought-after commodity in the labour market”. Employment figures and statistics after university graduation (at all levels) across the UK are widely used by the government as policies seek to demonstrate higher education’s value to society. However, Coyte (2022) discusses how such figures may be misleading and may not reflect the value added by higher education, especially as such figures focus too much on “highly skilled employment”. Thus, as a major policy concern, employability is re-defined, not only as a function of universities, but also as a mediating discourse between government,
universities and employers with an emphasis on economic return and with little evidence that supports the need for this political agenda (Boden and Nedeva, 2010).

In their report, Smith McGloin and Wynne (2022, p.7) identified some priorities common to Graduate Schools (or equivalent) that include: improving the quality of graduate education, the health and well-being of students, the student experience, and sharing good practice in supervision. Working as a university researcher at all career levels is a unique role in a unique environment best described as “research culture” (The Royal Society, 2022). The concept of research culture is a “complex and interconnected set of conditions and behaviours affecting researchers and their working environment” (Wellcome, 2020, p.7). For the present study, issues of supervision, working environment in terms of support, peers, and norms in behaviour are all part of the research culture in which students are trained in research. In this sense, research culture is also involved in matters of transferable skills and employability as it influences researchers’ career paths (The Royal Society, 2022). Recent research has shown a decline in students’ satisfaction with research culture over the past three years (Pitkin, 2021). The research environment may contribute to the flourishing of students through supportive structures and supervisory teams, or it can impede the completion of doctoral studies when students feel unsupported, pressured or too isolated and has, therefore, attracted governmental policies’ attention recently. The government’s Department for Business, Energy and Industrial Strategy (BEIS, 2021, p.6) was recently published to identify improvements
to positively impact the culture of the research and development system, especially in light of issues reported by Nuffield Council on Bioethics (2014); Wellcome (2020); Russell Group (2021) and The Royal Society (2021). While many concerns exist surrounding the impact of the research culture on students’ health and mental well-being (Smith McGloin and Wynne, 2022, p.64), a supportive supervisory team in the context of interdisciplinary research training is paramount (Lyall et al., 2008). Supervision from members from different disciplinary specialisations may be challenging (Vanstone et al., 2013) and was shown to be a complex process (Friedrich-Nel and Mackinnon, 2013). The situation is made more difficult considering supervisors may not feel supported, valued or rewarded in roles that affect their workloads and puts strain on their time for other activities (Gower and Clegg, 2021; Smith McGloin and Wynne, 2022). In examining CDT-OPTIMA students’ views on their training programme, attention is paid to supervisory arrangements and peer relationships in the context of student support.

In addition to the reviews discussed above, other reports and reviews have been influential on research training and universities. Wellcome, a charitable research organisation, published a report on their biomedical PhD training (Coriat et al., 2018). It identified similar concerns as discussed above, namely, publication and time pressure, support, training, and poor mental health. The Teaching Excellence and Student Outcomes Framework (TEF) was reviewed and reported on by Pearce (2021), calling on universities to demonstrate students’ “educational gains” in their excellence assessment. Educational gains, the report notes (p.10), might include knowledge, skills,
experience, work readiness, personal development and resilience.” The concept of students’ gains in education was piloted across the UK university sector as “learning gains” in a bid to find a common measure (Kandiko Howson, 2018) but was found impossible to apply across all institutions and subjects, despite government’s ambitions (p.6).

Overall, since the Harris review of postgraduate education in 1996 (see Hogan, 1997), it is fair to say that governments’ and sector organisations’ interests in the UK doctorate have greatly increased compared to the previous decades. These reviews were accompanied by many more reports on UK universities directly, thus affecting student training, such as the Dearing report (The National Committee of Inquiry into Higher Education, 1997), SET for success: The supply of people with science, technology, engineering and mathematics skills (Roberts, 2002), the Lambert review of business-university collaboration (Lambert, 2003), the Browne Review of Higher Education Funding and Student Finance (student tuition fees) (Hubble, 2010), and Paul Nurse’s review (Nurse, 2015) into the research councils.

The reports and reviews discussed above provide the context for postgraduate education that currently exists in the UK and were important in shaping how doctoral training is presently funded and delivered. These reports were accompanied by science policies designed to maximise value for the government’s investments in research and innovation and to capitalise on academic research (see Flanagan et al., 2019, pp.58-78 for a timeline of
science policy milestones in the UK). A PhD education is no longer the training of a small elite to access university positions. At present, a doctorate is also expected to prepare students with a breadth of skills that will make them employable in any sector, preferably for “highly skilled” jobs, and to contribute to the social and economic well-being of the country. This is especially true in the life sciences field, such as CDT-OPTIMA’s biomedical training to produce leaders and innovators who will respond and find solutions to major healthcare crises. Nevertheless, these future scientist-entrepreneurs are also trained for the purpose of solving Cardwell’s riddle (section 3.2) and fulfilling the UK Government’s vision to grow its international standing in the field. How this relates to the expectation that academic science will increase the country’s economic productivity and society’s welfare is discussed in the following section.

3.5 The role of academic knowledge in society

Until relatively recently, academic research was judged by an assessment of published peer-reviewed papers. In fact, it has often been said that research is not finished until it is communicated. However, this view is becoming outdated; it is more appropriate now to state that research is not finished until it has changed something for the better; in other words, it needs to have impact. (McKenna, 2021, p.5)

Academic research is increasingly expected to benefit society, as per McKenna’s quote above, as part of the UK Government’s vision to solve Cardwell’s riddle. The need to innovate and make scientific knowledge productive for the country's economy has led to new ways of training researchers in universities, alongside the training traditionally offered in
academia. The crucial role attributed to knowledge in developed societies dates back to the 1960s and the rise of new science-based industries (Powell and Snellman, 2004). The present era is known as the so-called “knowledge society” (Felt and Wynne, 2007) or “knowledge economy” (Mangabeira Unger, 1996), in which universities and education are perceived as the major drivers for economic prosperity (BIS, 2016; Santiago et al., 2008). This reliance on knowledge and its growth is more usefully understood in terms of impact.

**Research impact**

Requirements for the translation of academic knowledge into innovations have long been a preoccupation of the government, especially in relation to biomedicine (Myfanwy et al., 2011), and were re-articulated in the Dowling review (Dowling, 2015), commissioned to inform the government on ways to support the development of effective collaborations between universities and industry. The report claims the UK’s excellent academic base and innovative businesses do not connect to reap the potential of the science produced in universities and affirms the crucial role of government in supporting long-term partnerships between academia and industry to focus on use-inspired research that will benefit all participants and make “an important contribution to UK economic development” (p.29). Research impact is defined and currently monitored through the Research Excellence Framework (REF)\(^3\) as “the effect on, change or benefit to the economy, society, culture, public

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\(^3\) REF 2021. Guidance on REF2021 results. Online [https://ref.ac.uk/guidance-on-results/guidance-on-ref-2021-results/](https://ref.ac.uk/guidance-on-results/guidance-on-ref-2021-results/) [Last accessed 06/07/2022].
policy or services, health, the environment or quality of life, beyond academia. In 2020, UKRI announced the scrapping of the Pathways to Impact requirements in grant proposals\textsuperscript{32}, but a search of the current funding schemes across the research councils shows they continue to include “impact and strategic relevance” in their assessment criteria\textsuperscript{33}. In addition, UKRI has since created Impact Acceleration Accounts (IAAs)\textsuperscript{34}, an investment of over £117 million over three years (2022/25) for “strategic awards providing funding to research organisations to use creatively for a wide range of impact activities”. Universities depend greatly on the results of the REF exercise (which usually takes place every 5 or 6 years) for funding and reputation, and research impact is an integral part of academic practices to enable researchers to demonstrate the value of their research (McKenna, 2021, p.6). In this context, the REF can be understood as a process to ensure that new research is innovative, undertaken in partnership with industry, and collaborative, thus is often described as interdisciplinary. While most university research remains disciplinary based, the policy rhetoric, the REF, and the research funding instruments exacerbate a tendency for research to be labelled as interdisciplinary.


\textsuperscript{33} UKRI. Future Leaders Fellowships round 7. Online https://www.ukri.org/opportunity/future-leaders-fellowships-round-7/ [Last accessed 06/07/2022].

The pursuit of such research requires universities to build a workforce of scientists and researchers capable of delivering impact: thus, it also influences postgraduate education aimed at training future interdisciplinary leaders and scientists. The impact agenda of the government and its research councils have raised many criticisms and heated debates among academics, even though researchers commonly agree that research should benefit society (Smith et al., 2020, p.27).

Some scholars point to negative and unwanted “state interventions” (Olssen and Peters, 2005) and to policies that increasingly emphasise an economic utilitarianism of education (Bell and Stevenson, 2006, p.3). Such trends are at the origin of strong responses from policy actors and a vast literature critical of neoliberalism or the importance of competitive markets in all areas of social life (Springer et al., 2016, p.2). In higher education, these policies are also viewed as making universities subservient to the economic imperative, leading Olssen and Peters (2005) to warn of coming “education wars”, a struggle over the meaning and value of knowledge and the possible privatisation of knowledge production. Additionally, there are indications that research and educational policy expectations are rarely delivered in practice. For instance, policy may be driven by power-vested interests and disguise the fundamental forces behind new incentives (e.g. Teitelbaum, 2014), credentials may devalue in a mass-educational market (Alvesson and Benner, 2016), and the link between education and economic growth is not clear-cut (Hanushek, 2016). Other scholars dispute the perceived value of
interdisciplinary science, which they claim may be more ideological than reformist in its relationship to science education (Allen, 2017).

There are stark warnings that interdisciplinarity can function as a “fantasy of a grand unified theory of knowledge” only to produce amateurs instead of experts (Davis, 2007). Similarly, Graff (2015, p.2) questions the economics of interdisciplinarity and warns that “exaggerated and unrealistic expectations abound”. In sum, the interdisciplinary research agenda is often promoted as inherently positive (Shove and Wouters, 2005), and interdisciplinarity has become a buzzword in policy circles and academia (Krishnan, 2009) despite repeated warnings about the challenges of interdisciplinary working practices (Chettiparamb, 2007; Demharter et al., 2017; Lyall and Fletcher, 2013).

**Accountability**

The impact of science and research can be understood in two ways in the UK and the REF assessment: academic impact refers to researchers’ contribution to their field of knowledge, while the “external socio-economic impact” refers to the benefits for the economy and society (Penfield et al., 2014). Academic impact is a measure of individuals’ publications and citations and has been found in STS research to be a measure of the quality of candidates for academic posts, if not the quality of research (Langfeldt et al., 2021), although this may differ by countries (Haddow and Hammarfelt, 2019) and disciplines or fields of studies (Smith et al., 2020, ch.4; Thomas, 2018, p.124). It follows then that academic impact is important to students who want to progress in an academic career because, in the words of
Dahler-Larsen (2014), publications are a way to “earn points” and impact academic careers (Smith et al., 2020, p.92). Many of the studies regarding the evaluation of academic impact also report much ambivalence towards such indicators, expressing resistance, disbelief, or frustration with the research evaluation policies that are in place (Haddow and Hammarfelt, 2019), damaging or counter-productive effects (Collini, 2020), or discussing “bad impact” due to the limitation of the current approaches (Smith et al., 2020, p.60).

Academic impact and impact outside of academia are primarily ways for the government to demonstrate the value of investments in science to their stakeholders and the wider society (Khazragui and Hudson, 2015; Morton, 2015). Universities are also concerned with the rankings developed from impact assessment for competition, marketing and the use of rankings as a proxy for the satisfaction of fee-paying students (Alvesson, 2013b; Penfield et al., 2014). The scholarly study of metrics has vastly increased in line with the government’s strategies to demonstrate the value of research and consists of separate but often confused fields: bibliometrics, scientometrics, informetrics (Hood and Wilson, 2001) and altmetrics (Robinson-Garcia et al., 2018) but impact is multidimensional and not often easy to identify. For example, the number of spin-out companies or intellectual patents and associated income are easily measured, but economic and societal benefits are more uncertain (Khazragui and Hudson, 2015).
The REF (and its predecessor, the Research Assessment Exercise) has been particularly challenging for the evaluation of interdisciplinary research, which does not fit the usual disciplinary quality indicators (Lyall et al., 2011b, p.98). The latest REF exercise of 2021 shows a willingness to engage with interdisciplinary research outputs for a fair assessment but continues to show challenges for the experts’ panel (Interdisciplinary Research Advisory Panel, 2022). The evaluation of interdisciplinary research is notoriously difficult to achieve and, to date, interdisciplinary studies scholars have failed to agree on and adopt a shared discourse of “appropriate, explicit, reliable, and comparable approaches ‘that supports meaningful dialogue across instantiations’ of interdisciplinarity” (Laursen et al., 2022). The IRAP was faced with appointing suitable members to produce additional guidance for interdisciplinary outputs and identifying assessment mechanisms (p.5) and reported the following issues: categorising research outputs as interdisciplinary (p.14), maintaining a plurality of approach and flexible mechanism to the assessment of interdisciplinary research (p.15), provide clearer guidance to the research community for interdisciplinary submissions (p.16). Importantly for this study, the report identified a problem due to the inconsistent use of the interdisciplinary flag by institutions (p.1), which, I would argue, may be due to the plurality of understandings of interdisciplinarity (Vienni-Baptista et al., 2022) and inconsistent definitions (section 2.2). The difficulty of evidencing interdisciplinary research impact through the REF is one of the barriers to progression in academic careers.
associated with the historical disciplinary organisation of institutions (section 2.1.1).

Whereas the REF is a means for government, researchers and universities to demonstrate the (positive) value of UK research, it can also lead to unintended consequences of game-playing (Khazragui and Hudson, 2015; Smith et al., 2020, p.35). Viewing academic work as a “research game” (Lucas, 2001) with a focus on publications only serves to increase the volume of literature for the only sake of gaining advantage in a competitive sector because “when a measure becomes a target, it ceases to be a good measure” (Mattson et al., 2021). This phenomenon is what Alvesson (2013b), discussing organisational studies, describes as “careerism”, where some scholars are now more interested in where and how much they have published rather than what they have contributed, and an “intra-tribe” orientation in which scholars publish purely to obtain (or maintain) status among peers in the same field. In his forceful criticism around the current state of research, Alvesson also points out the explosion of publications that have nothing new to say, publishing for the brand (individuals’, or at best, institutions’ prestige), and laments chasing the rankings. In other words, Alvesson talks of a movement from research to roi-search (Return On Investment), a type of academic game that seeks (egoistic) return on investment instead of contribution to knowledge. Alvesson’s appraisal of the situation may seem overly harsh or too generalised but in academia, the
culture of “publish or perish” is unfortunately too well known\textsuperscript{35} (Barton and Merolli, 2019; Doyle and Cuthill, 2015; Hills, 1999), whether it is real or imaginary. Finally, Alvesson \textit{et al.} (2017) also call for the social sciences, more generally, to produce meaningful research rather than for publishing sake. In the context of the present study, the pressure on students to publish while in graduate school may be real or perceived as such, regardless of whether institutions, supervisors, disciplinary norms or other forces are at work, with little understanding of whether reproducing such concept is helpful\textsuperscript{36}. Within this context, government and research councils are seen as setting constraints and enablers on what academics and universities should do, thereby “setting up the rules of the game” (Harlow, 2020, p.2).

### 3.6 The politicisation of science
Since the government invests funds in research, it seeks to reassure its stakeholders of the value of science and needs a legitimate mechanism for accountability, one of which is the REF assessment exercise. The expectations of economic and societal benefits from research have long been influential factors in the shaping of science and its institutions (Martin, 2003) and may date as far back as ancient Athens (McKenna, 2021, p.5). However, the imperative to produce technological innovations from science is more important than ever and has produced changes in how doctoral students are


\textsuperscript{36} Behavioural and Social Sciences, Mills-Finnerty Colleen, 10 October 2019. Is it really “publish or perish” for PhD students? Online https://socialsciences.nature.com/posts/54676-is-it-really-publish-or-perish-for-phd-students [Last accessed 08/07/2022].
trained and for what purposes, as well as how universities are required to account for their activities. Reconciling the needs of government with the traditional values of academic practices has been shown to create tensions and paradoxes.

Firstly, there is a problem with the autonomy of science, which is seen to be impinged upon by what some have called the “politicisation of science” (Khazragui and Hudson, 2015; Weingart, 1997). Universities are now, more than ever, under pressure to produce tangible benefits to society and are under heightened scrutiny from the government to ensure a return on investment while also being responsible for excellent research (Brown, 2014). For some scholars, this is akin to a “regime of performativity” where performing is everything so that more publications lead to more research grants and more students (Thomas, 2018, p.110). The problem of interference by the government is not a new issue, as attested by Berdahl (1990), who argued, more than three decades ago about British universities, that “substantive autonomy may be jeopardised by making universities into weather vanes in the face of strong societal demands.” The warning is clear that academics should not forgo the traditional values of academic research in the pursuit of impact (Khazragui and Hudson, 2015).

In the STS literature, the demands made by government for the usefulness and commercialisation of knowledge, how to train new researchers or the perceived need to innovate in academia amounts to a politicisation of science (Weingart, 1997). However, Brown (2014) makes useful distinctions in the
conceptions of politicisation, claiming the adage “science is political” has outlived its usefulness in a world where institutions are already always political. Following Brown’s distinctions, I contend that the concept of “science as a site of politics” places a greater emphasis on the practices of politics and their entanglement with the practices of science.

In studies of higher education and policy, Etzkowitz (2016), Watson et al. (2016), Molas-Gallart et al. (2012), Clough and Bagley (2012) termed the demands made on knowledge as a “third mission” or “third stream” of universities. University third stream activities refer to “the generation, use, application and exploitation of knowledge and other university capabilities outside academic environments”, thus “interactions between universities and the rest of society” (Molas-Gallart et al., 2012, pp.iii-iv), which run alongside first and second streams, teaching and research respectively (Watson et al., 2016). These third mission activities of universities are related to the “triple-helix” (Etzkowitz and Leydesdorff, 1997), which refers to relationships, and knowledge flows between universities, industry and government with the aim to translating research into use (Etzkowitz, 2018), thus, the third mission and triple helix both encapsulate the UK’s research and educational policies’ aspirations to foster technological advances through tighter relationships of stakeholders, the way they communicate and to change their current practices to maximise benefits from academic research. It can also be said the third mission of universities has been instituted in response to the challenge of solving Cardwell’s riddle. One of the tools used to measure the quality and impact of research in the UK, the REF (discussed earlier), is now
implicated in some understandings of this situation and what is known as the "paradox of management". That is, the need for universities and academics to be accountable to government and other stakeholders, partly through the REF, has seen a rise in management practices in higher education. Attempts by the UK Government to streamline and organise the activities of universities according to a corporate model is thought to date back to the mid-1980s (Deem et al., 2007, ch.2; Ferlie, 2017). This new form of management – known as new public management - was driven by cuts in university funding and efforts to introduce efficiency savings and a focus on academic performance and public accountability (Deem et al., 2007, p.65).

While academia has always sought to maintain autonomy from the government, it is now characterised by an audit culture and a vast increase in number of university managers, that Collini (2020) for example, characterises as damaging consequences that reduce universities' value to society.

The somewhat bleak perspectives surrounding universities and their academic practices discussed in this section should be understood in the context of academic discontent regarding the policies and politics of decades of governmental decisions that have sought to tie economic productivity and academic knowledge in ways that influence academic practices widely, and therefore also the training and the future of doctoral students. As Collini (2020) points out, though, it should be noted that academics have been complicit in this situation. Hence, the evolution of universities and doctoral training is not to be understood as purely political but also academic.
Universities and researchers are complicit in instituting policies through the idea of *playing the game for REF* (section 3.5).

### 3.7 The political economy of knowledge

The UK Government’s efforts to make universities and academics accountable to society (section 3.5) through new public management strategies are linked to a logic of capitalism in which knowledge is seen as a form of capital (Andersson, 2009, p.24). Whereas the early universities trained a few students to supply society with educated professionals (section 2.1.1), they are now expected to deliver innovations, ensure students’ employability and increase the pace at which knowledge is made available to society (Sørensen and Traweek, 2022, p.159). This market orientation of policies has led to the notion of “academic capitalism”, whereby universities are involved in the maximisation of economic profits (Münch, 2020) and the commercialisation of public science (Fini *et al.*, 2018). The pursuit of the translation of knowledge into economic activity has given rise to the concept of “the entrepreneurial university” driven by metrics (Etzkowitz, 2016) and strengthened new public management control (Deem *et al.*, 2007). The economic contribution of universities to society also includes their spending power and the employment they provide. In a recent report, Universities UK claims that “Universities in England contribute around £95 billion to the economy and support more than 815,000 jobs across England”.

However, the UK Government’s strategies are firmly focused on science and

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technology as sources of capital for international competitive advantage (Carayannis and Campbell, 2012, p.2), especially in fields that encompass STEM capabilities, which are thought to be of high value to industry, thus to the economy (section 3.4). Therefore, the political value placed on STEM fields, knowledge and innovation holds the potential for great economic worth or the political economy of knowledge (Andersson, 2009). Conversely, in the UK and elsewhere, the political value placed on skills and education for the economy is known as the “political economy of (high) skills” (Durazzi, 2019; Lloyd and Payne, 2003) and the “political economy of education” (Brajkovic, 2018; Cowen, 2019).

From a narrow economic framing of the relationship between education, skills and the economy, UK policies tend to treat students as future workers and consumers (Saltman, 2018, p.13). In the case of the life sciences, Saltman (2018, ch.6) further argues the emergence of “biopolitics” based on the study of life where education is valued for-profit and students learn to be successful entrepreneurial subjects. This political perspective is based on the promises that higher education leads to high skill jobs and the government’s visions for the creation of CDTs, as discussed in section 3.3. As some scholars have argued, such visions for education amount to the formation of subjects as the right kind of scholars (Sørensen and Traweek, 2022, p.112), especially the scientist entrepreneur that CDT-OPTIMA seeks to train (section 1.3.2). Consequently, the entrepreneurial university (Etzkowitz, 2016) in this thesis is also understood as a utilitarian university – a business based on the production and consumption of material goods (Rosso, 2019a) and subjects.
Chapter 3 has provided the UK political background necessary to understand the government’s vision for technological progress through innovation in order to gain a competitive position internationally and to make the UK a science superpower. Ways in which countries seek to develop their innovations from academic knowledge were presented as Cardwell’s riddle to examine the importance placed on translational science and its part in the government’s strategy (section 3.2). Efforts to produce the future scientific workforce of the UK have led to new models of doctoral training and several reviews of the UK PhD, pointing to a focus on STEM subjects and collaborative interdisciplinary research (sections 3.3 and 3.4). Section 3.5 examined how policies have attempted to make scientific research more impactful and accountable for society. Finally, the last two sections of chapter 3 discussed some resultant consequences for science and universities. The following chapter presents the methodological choices made in the present study to answer the research questions posed in section 1.2.3.
Chapter 4  Methodology

4.1 Introduction

This thesis examines how UK interdisciplinary policy strategies are enacted in doctoral training to provide evidence into the underpinning logics and consequences of interdisciplinarity in universities. Chapter 1 introduced the background context for this study, its aims and objectives and a research framework. Chapter 2 explored and synthesised the extant literature, mainly from STS and educational research fields, that situated and informed the whole study. This chapter details the methodological approach used to design and carry out the research by discussing my philosophical orientations (section 4.2), describing educational ethnography (section 4.3) and the literature search method in section 4.4. Section 4.5 details the data collection stage of the project, and section 4.6 discusses the use of the grey literature. Section 4.7 presents a rarely acknowledged iterative data analysis framework grounded in mapping to aid with the visualisation of the data and the thematic analysis. Section 4.8 examines my position as a PhD student researching other PhD students and issues surrounding “insider research” in universities. In section 4.9, I discuss issues relevant to ethics, and finally, section 4.10 provides a critique of the research design.

4.2 Philosophical orientations

Knowledge is primarily about partaking in a reality.
(Mol, 2002, p.154)

The starting point for my engagement with the research topic was a belief that to learn about a phenomenon, a researcher has to engage with it, or as
Mol puts it in the quote above: partake in a reality. Conducting research in one’s own institution has provided both advantages and challenges in terms of positionality (see section 4.8) but also presented the opportunity to experience the day-to-day activities of my participants and, thus, to engage with and enact my research within (part of) their social realities. Whether there has been a “turn to ontology in STS”, as claimed by Woolgar and Lezaun (2013), Mol (2002) and Joks and Law (2019), during this project, I have come to understand the world and reality through the enactment of practices. As such, I also adhere to the thought that practices can be enacted differently and can generate ontological multiplicity (Joks and Law, 2019). Thus, singular nouns used here should be read as plurals, such as “realities”, “worlds”, and “ontologies”. This discussion regarding ontology points to the difficulty in making objective determinations of reality (Woolgar and Lezaun, 2015), which were not the aim of this study that is firmly situated in the qualitative interpretivist paradigm (Blaikie and Priest, 2010, p.99; Patton, 2015, p.5).

An interpretive way of knowing focuses on context-specific meanings through what people do and say in this specific context (Ritchie et al., 2014, p.22; Schwartz-Shea and Yanow, 2012, p.23). The problem this thesis aimed to examine started with the constatation that interdisciplinary research is much talked about in academia. It is used as a mode of knowledge production and research training of doctoral students and advocated in UK policies, despite widely held ideas that research and education are organised through disciplines (Kreber, 2009). Thus, the choices made in the research design
are a result of my philosophical orientations towards what happens in practice, how realities are performed, the focus on human interactions and an openness towards uncertainty. It is in this context that the present study evolved, leading – eventually - to the methodological approaches discussed in the following sections. After all, “if you know where you will end up when you begin, nothing has happened in the meantime” (Massumi, 2021, p.19).

4.3 Educational ethnography
Focussing on doctoral practices in an interdisciplinary programme meant building a research framework that would allow:

- Lengthy and continuous access to participants in their everyday settings.
- To identify who, what and when to observe.
- Access to participants’ perspectives and their understandings of their experiences.

An ethnography in education (Maeder, 2018, p.168), which investigates what happens in an educational system, focuses on learning as a practice that is situated within cultural-discursive, material-economic, and social-political arrangements (section 2.3.5). Thus, what happens in practice (section 4.2) is the locus of this educational ethnography that centres on participants' sayings, doings and relatings in their everyday experiences. As such, the present study does not take educational institutions for granted, as asserted by Maeder (2018, p.168), and questions how interdisciplinary doctoral training practices emerge and co-exist with other academic practices.
In the last few decades, ethnography has grown as a tradition in educational research and has evolved into multiple modalities (Beach et al., 2018, p.21; Wieser and Pich Ortega, 2020), but it is still found to be too rarely adopted in studies of higher education (Forsey, 2020, p.15; Pabian, 2014). Educational ethnographies have nevertheless been found efficacious when applied to higher education (Trowler, 2014b; Wieser and Pich Ortega, 2020). The method was chosen to illuminate how interdisciplinary doctoral training is enacted by the participants in this study, in contrast with how interdisciplinarity is understood in UK policies (see research questions in section 1.2.3). Schatzki (2012, p.24) contends that the only way to acquire knowledge about educational work is to practise “interaction-observation”, that is, ethnography. Therefore, a study into the practices of interdisciplinary doctoral training lends itself particularly well to an educational ethnography.

In order to claim that a study is of an educational ethnography type, it needs to meet some specific criteria, although ethnographic practices can be thought to be fluid (Forsey, 2020, p.15). Ethnography dates back to colonial times and administrative practices and then became the professional ethnographic practice of anthropology (Miettinen et al., 2009) before reaching other disciplines. Hammersley (2018) argues ‘ethnography’ comes in many different versions and Atkinson et al. (2010, p.464) point out there was never “a traditional, hegemonic ethnographic order”. However, ethnography remains a method to gain an understanding from the perspective of the participants by immersion into their locale and observation of their daily experiences (Forsey, 2020, p.23). There needs to be long-term engagement,
the use of multiple research methods, and the generation of rich data (Walford, 2018, p.38). Moreover, if interdisciplinarity stands in contrast to disciplinary specialisation, an ethnography of interdisciplinary doctoral practices can help highlight differences and introduces the concept of unfamiliarity, which is necessary for ethnography (Trowler, 2014b).

Originally, the research design included a comparison of CDT-OPTIMA students’ experiences with students on imaging programmes at the University of Edinburgh but not in a CDT. This decision was informed by the insights gained from the pilot study (section 4.5.1) and aimed to investigate the effects of the CDT model for doctoral training. Attendance at a “PhD Imaging Expo” at the University of Edinburgh in late 2018 was an opportunity to contact potential participants and allowed me to contact two specific gatekeepers who had agreed to facilitate access to participants and facilities. CDT-OPTIMA was identified as a priority for the data collection since the CDT partly funded my scholarship, so data collection with non-CDT students was planned to take place later in the project. These plans were curtailed by the coronavirus pandemic and prolonged confinement starting early in 2020, requiring me to change the research design substantially. Due to the uncertainty around the length of lockdown, I chose a desk-based exercise to analyse policy documents pertaining to doctoral training, universities and interdisciplinarity. Subsequently, the situation required an adjustment to the literature review, research questions and data analysis. In my opinion, this change has led to a richer study that has examined interdisciplinary doctoral training not only from the perspectives of students but also through an
understanding of why this type of PhD is currently on the rise in the UK and elsewhere.

Research and training at postgraduate level encompass a multitude of practices and, therefore, involve a level of ‘messiness’ (Jones, 2011), whereby multiple practices are connected, interconnected and even, sometimes, can come into tension (Shove et al., 2012b). “Close-up research”, such as the type enacted through ethnography, can occlude the wider structural elements of a situation and fail to integrate different levels of analysis (Trowler, 2012b). However, this praxeological study was conducted on different levels: a focus on interdisciplinary students’ doctoral training, interdisciplinary research in universities and interdisciplinary governmental policies. That is to say, this study has resulted in the study of interdisciplinarity at the micro, meso and macro levels from individual practices to those of universities and the macro processes of the political level. The complex of practices analysed in the present study goes beyond the microscopic perspective of interaction or the macroscopic analysis of policies (Wieser and Pilch Ortega, 2020) and focuses on phenomena that happen in the moment. This multi-level perspective has been a reminder that the activities of individuals, institutions of higher education and policymaking are tightly intertwined. Hence, I sought to present an account of interdisciplinarity that is the result of many processes rather than a specific characteristic of research, researchers or policies.
4.4 Literature search method

The present study was carried out based on multiple and distinct sources from diverse research fields, challenging existing search strategies such as those available in the scholastic (traditional) and the interventionist (systematic) research traditions (Hart, 2018, ch.4). Issues concerning interdisciplinarity can be found in almost all disciplines, and research on doctoral education spans fields such as higher education, studies in higher education, higher education research and development, scholarship of teaching and learning, and many others. As a field of research, STS also offers numerous modes of thinking and forms of knowing. In this study, concerns about policies have also led to an engagement with policy-relevant literature such as research policy, education policy, science and public policy.

A lack of an existing corpus that connects these disparate yet essential research fields for the production of this thesis has proved complex for the search of sources to identify previous studies, methods, theories and concepts. Meticulous database searches such as Academic Search Complete, JSTOR, Scopus and Web of Science, as well as online library searches, yielded thousands of results, of which very few were relevant to the topic of this study. Searches included the following terms with wildcards to access as many matches as possible and Boolean operators to combine the terms: interdisciplinary, interdisciplinarity, graduate, PhD, doctoral, education, training and science. Most sources were dismissed as being outside the scope of the present research, such as teacher training and development, gender studies, multicultural studies, or those in remote fields.
(for example, dentist training). The relevant literature was downloaded in a reference manager (EndNote), read, and notes were kept in a research diary.

In view of the challenges discussed above, the literature search strategy consisted of snowballing, which includes reference and citation tracking, as described in Greenhalgh and Peacock (2005). The snowballing method, including drawing on existing knowledge from supervisors, electronic searches, subscriptions to publishers’ email lists and serendipitous discovery, proved powerful and efficient for locating sources, as was found by Greenhalgh and Peacock (2005). In addition, and whenever possible, the most recent research has been used throughout the thesis to keep abreast of the fast-developing literature on doctoral education and interdisciplinarity.

### 4.5 Data collection

The primary data collection method chosen for this multi-method project is participant observation to focus on what is happening in the environment and “being in the moment” (Roller and Lavrakas, 2015, p.181). Data was collected between 2017 and 2020 at the University of Edinburgh and the University of Strathclyde in various locations and settings, although the main data collection stage of the project started in 2019. A breakdown of data collection activities is given in figure 9. In addition, a group interview (section 4.5.1), formal interviews (section 4.5.3) and informal interviews (section 4.5.4) were carried out to produce a rich understanding of the participants’ everyday practices and relationships.
Most of the data were captured during fieldwork (except for the grey literature, discussed in section 4.6) using written notes and reflections, which were sometimes typed up and stored electronically. The amount of data collected did not allow time for all observations to be translated to an electronic format, but an index of notes was kept to ease retrieval and to allow the organisation of the materials. Interviews were recorded and transcribed (see section 4.5.3).

The data collection strategy is, thus, ethnographically informed and is well suited to educational research (Mills and Morton, 2013, p.2) with the advantage of multiple methods for depth of exploration (Creswell, 2013, p.465). Ethnography is thought to rely on three imperatives; time, depth and field (Epstein et al., 2013) in order to produce rich understanding or “thick descriptions” (Leeds-Hurwitz, 2019). Thick descriptions, as originally coined by Geertz (1973), refer to the level of analysis of data that goes beyond mere observation, in which the ethnographer must first grasp the complexity of the field before attempting to render a written account. And as Geertz (1973, p.311) puts it, “if you want to understand a science, you should look in the first instance, not at its theories or its findings, […], you should look at what the practitioners of it do.” Studying a living practice and relating it to larger institutional contexts is a challenge (Miettinen et al., 2009) but an immersion in the here and now produces observations of practices as they happen, and the derived data is thought to provide rich and authentic accounts (Cohen, 2018, p.542). Doctoral training activities consist of multiple practices made up of sayings, doings and meanings, as discussed in section 2.3.4. By
experiencing and observing the day-to-day activities of my participants, I aimed to gain first-hand knowledge of how they developed their research skills and competencies in a variety of settings (presentations, lectures, meetings, labs, and others). The way in which these elements are integrated forms patterns of action over time and defines what doctoral training or interdisciplinarity mean in the situation observed. In this practice theoretical perspective, students are constituted through the moulding of bodies in practice (Sedlačko, 2017) where discourses, resources and relationships play a crucial part in enabling or constraining what students are able to do (see section 2.3.4). Taking doctoral training and interdisciplinarity as practices, instead of entities, places the focus on how students become scientists and how they develop a professional identity (Jowsey et al., 2020) rather than on the outcome of education in terms of what can be measured (Biesta, 2009) and has also facilitated my own reflection on my position as a researcher (see section 4.8). This perspective acknowledges that practices are heterogenous and helps make an important distinction between what might be my own experiences and those of my participants.

The choice of an educational ethnography to study interdisciplinarity allowed me to remain immersed in my participants’ social worlds over a period of four years to produce thick descriptions of their practices, how these practices fit in with the traditional disciplinary practices of universities and allowed a comparison of interdisciplinary policy strategies with what happens in the specific field under study, thus providing answers to the research questions, as set out in section 1.2.3. I now turn to the specific methods used in this
study to demonstrate how the different types of data collected provided insights into interdisciplinary doctoral training. Figure 9 presented at the end of section 4.5 summarises the data collection techniques and their purposes.

4.5.1 Group interview

At the end of the master’s stage of this study in 2018, I conducted a group interview with six CDT-OPTIMA students. At the time, CDT-OPTIMA had recruited four cohorts of twelve students, and the group interviewed included students from all the cohorts. The group interview had two aims: one was to be a pilot study to test the feasibility of the method as well as to gain experience and insights for future research directions. The second aim was to collect data for the purpose of co-presenting an empirically based paper (non-published) for the QAA 15th Enhancement Themes conference in Glasgow on 7th June 2018, in collaboration with three members of CDT-OPTIMA management group. The paper, entitled *Creating a home for interdisciplinary research students – a case study* examined how students are supported in their development as interdisciplinary researchers, their sense of belonging, community and identity. These themes were set out prior to the group interview, as agreed with CDT-OPTIMA management, in order to address the conference themes (see appendix A) for the schedule of semi-structured questions) and underpinned the data analysis.

4.5.2 Participant observation

As per figure 9, participant observation took place in a variety of settings where I could observe my participants engaged in the practices of doctoral
work. Strong consideration was given to the diversity of locations and activities chosen for observation and the type of data required to address the research. From a practice theory lens, thinking about where to observe practices is a matter of what Shove et al. (2012a, p.7) call finding a viable practice space. Due to the dispersion of CDT-OPTIMA students across multiple universities, labs and disciplines, and with the time constraints to complete a doctoral thesis, I chose to observe my participants in places where they were in interaction with each other rather than purely observing work in labs, which is often understood in STS as the sites where science is constructed (Ziewitz and Lynch, 2018). However, observing during lectures, presentations and summer schools was found to be more efficient in producing data and insights on how students construct themselves through practices and in a collective manner. That is to say that I was not only able to observe students’ activities but also to apply a sensibility for the relationality between the students themselves and the students and other individuals they interacted with during the course of their activities (invited speakers, supervisors, CDT-OPTIMA management, lecturers, among others). The term sensibility here is a recognition that conducting an ethnographically informed study from a practice theory requires a sensibility to practice, as demonstrated by Sedlačko (2017). A sensibility for practice, as per Sedlačko (2017, p.54), involves four principles: 1) a focus on what people actually do, 2) a focus on everydayness, 3) a focus on the work of assembling, structuring and ordering (of practices), and 4) reflexivity. Similarly, I define a sensibility to relationality as being conscious of people’s interactions in the
sense that they are a part of their practices (Depelteau, 2018, p.5). Scholars of practice theory are divided regarding aspects of relationality and disagree over the importance of the concept. For example, Schatzki (2019, pp.173-175) cautions not to overemphasise relationality as it does not alone compose social life (discussed in section 2.3.4), whereas Schäfer (2017) is explicit about his relational views. However, choosing to proceed with a sensibility for relationality allowed me to background the relational aspects of doctoral education as a tool to investigate in more depth the insights uncovered during the group interview, such as concepts of belonging, identity and community.

The participant observation process

The observation process was greatly aided by being immersed in CDT-OPTIMA, where students were familiar with my presence, had given their written consent for the research and had knowledge about my status as a PhD student and my project. Issues of ethics are dealt with separately in section 4.9. I would normally sit unobtrusively at the back of the room to observe as many participants as possible and mostly always with a notebook to jot down notes and thoughts as they happened. There were times when taking notes would be too distracting for my own participation, for example, during meetings with patients, in which case, I would write down notes just after the event. Most of these notes were indexed and collated in a folder and revisited at a later stage when I would write reflections on my experiences.
and thoughts. Very few of these notes were ever typed up and digitalised, but possible themes were highlighted for data analysis purposes.

An excerpt of my notes during the summer school of 2019 is reproduced here as an example of participant observation in figure 8:

<table>
<thead>
<tr>
<th>4th Joint Medical Imaging CDT Summer School, Edinburgh 2-4 September 2019</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Participants:</strong> medical optical imaging PhD students training in CDTs in Edinburgh, Oxford, UCL and King’s College London</td>
</tr>
<tr>
<td><strong>Aims of the summer school:</strong> to share research, to network and to provide a space to learn and think about:</td>
</tr>
<tr>
<td>- The clinical pull as well as the technical push for new medical innovations.</td>
</tr>
<tr>
<td>- How to involve patients and clinicians in research as end users of technology.</td>
</tr>
<tr>
<td>- What investors, including VCs and large industries, are looking for in the application of research to healthcare.</td>
</tr>
<tr>
<td><strong>Description of the activity of “grand challenge”</strong></td>
</tr>
<tr>
<td>20 groups of about 7 students to work on one of three challenges. The challenge assigned to my group: “no two people have the same multiple sclerosis (MS). How can we use individual patients’ experiences of MS to predict the effect on them more accurately and to help personalise MS therapy?”.</td>
</tr>
<tr>
<td>Activity assessed at end of summer school through pitching sessions to the other students and experienced researchers. Student voting and winners chosen by the expert panel.</td>
</tr>
<tr>
<td>Winning presentation to be decided on 1) clarity of proposal, 2) innovation, 3) end-user engagement, 4) competitive advantage, 5) commercial potential, and 6) understanding of resources.</td>
</tr>
<tr>
<td><strong>Reflections on working on the grand challenge</strong></td>
</tr>
<tr>
<td>- What type of learning is achieved? Communication, teamwork, brainstorming. Worth considering this question further. Besides making sure ideas were economically sound, was there any real learning? Does this exercise contribute to the development of new researchers or the opening up of networks?</td>
</tr>
</tbody>
</table>
- “This isn’t for real, so it doesn’t matter”. How seriously were patients being asked about their issues? Problems of ethics: patients were very excited to hear students were working on their issues (outside the grand challenge) and had the impression that solutions were forthcoming. Evidently, solutions are coming, but how long will they have to wait?
- Closely related disciplines (optical medical imaging) or closely related goals? Although students belong to different CDTs, they all share similar aims to solve healthcare issues through use of optical medical imaging techniques. For me, this is collaboration between like-minded researchers rather than an invitation to work with other disciplines.
- Are patients heard and important in the question about commercialising new healthcare technologies?
- What (if anything apart from the PhD programme) is driving students to want to develop new technologies: patients/diseases, health services, society, innovation, economic incentives?
- What is special about translational research?

Figure 8: Excerpt from notes taken during fieldwork observation

The notes taken on this specific instance were also accompanied by a reflection on my own interests in taking part in the summer school and highlighted how I understood participant observation at the time. For example, I described how I was slightly anxious about being plunged into a different world as I am not a trained scientist (in the context of taking part in an activity), not being sure how much I could observe from my participants and whether this instance would provide useful insights (many students outside CDT-OPTIMA). These descriptive and reflexive notes proved useful later when carrying out more focussed observations and for iterating between data, theory and policy documents. For example, the quote “this isn’t for real, so it doesn’t matter” was closely associated with the idea that students perceive their training and the university environment as different from the “real world” (section 5.5).
Observation was at times considered ‘participant observation’ when I took part in the activities in which my participants were involved, such as taught courses, meet-the-patients sessions and a summer school. At other times, it may have been best described as non-participant observation when I refrained from taking part and was more a “spectator”. However, as I relied on interactions with my participants many times after the end of an event, and because the field included spaces that only insiders can access, I consider my role as participant observer.

Following Spradley (1980, cited in Flick, 2009, p.227) and my choice of iterative-inductive approach to data analysis, I approached participant observation from three different lenses.

1) Descriptive observation: descriptions of the field under study. What are the everyday practices of the participants?

2) Focussed observation: narrow my perspective to focus on research questions. For example, asking which practices are relevant when thinking about interdisciplinarity and whether they are different from other doctoral practices.

3) Selective observation: finding further instances of practices identified during the focussed observation. This step also took into consideration what I had learned from the participants verbally and tried to find either further instantiations or refutations of the phenomenon. The multiple presentations made by the students were a useful context, for example, for finding out how they represented the steps involved in
their study, from the understanding of the issue at hand, to why it was important to find novel solutions and how they thought they could arrive at this solution.

In practice, these different types of approaching participant observation are not so clear-cut and not chronologically arranged. This may be related to some criticisms of the unstructured observation approach, which presents the researcher with a lack of direction when choosing what to observe and how to analyse the information (Given, 2008b, p.908). Field observers have selective perceptions (Patton, 2015, p.333), and not everything can be observed in the field, but this is always a matter of researcher’s choice in qualitative research, where one has to decide who to speak to, where, what to ask and what to observe (Hammersley and Atkinson, 2007, p.35). For this reason, it was judged prudent during the present study to collect data in different contexts and through multiple methods to provide a depth of understanding.

4.5.3 Interviews

Interviews predominate in qualitative research, even in educational ethnography, which is first and foremost based on multiple research methods (Walford, 2018, p.39). Yet, all social actors have a detailed grasp of the knowledge, rules, conventions and practices that constitute their community (Atkinson, 2015, pp.16-17), and I considered carefully how best to gain access to this information from my participants. Interviews did not figure as a priority in my design for data collection until I asked all CDT-OPTIMA
students by email whether they wished to engage with my research and, if
so, what type of active role they would be willing to play. A group of students
responded they were interested in being interviewed individually so 1) they
could talk to me freely, and 2) the meeting could be scheduled into their day,
ahead of time and at a convenient location. This request was surprising to
me at first because of the success of the focus group pilot study I had carried
out earlier and my assumption that participating as a group was more
comfortable for everyone. Some scholars have pointed to a trend of the
‘interview society’ (e.g. Atkinson and Silverman, 1997; Gubrium and Holstein,
2001, ch1) and advise against the unreflexive use of the interview method
because participants not only represent their thoughts verbally but they also
enact specific worlds through language (Atkinson, 2015, p.93). From a
practice theory perspective, I consider the interview to be a relational practice
of humans in interaction (Martens, 2012) and take the interview as a
performance of the spoken word or a ‘discursive practice’ and a valid study of
behaviour (Swidler, 2001, p.76). Contacting CDT-OPTIMA students to ask
about their willingness to actively participate in the research is a form of co-
production that is thought to enrich research by learning from those affected
and interested in the project and promotes an equitable relationship between
researcher and participants38.

Interviews, as a method for data collection, were one way some of the
participants understood qualitative research and offered their participation.

38 UKRI, Co-production in research, 2022. Online https://www.ukri.org/about-us/policies-
standards-and-data/good-research-resource-hub/research-co-production/ [Last accessed
12/10/2022].
Following the enthusiasm of the three students who asked to be interviewed, I reached out to other participants and carried out three further interviews before the Covid lockdown.

**Interview technique**

I intended for the interview technique to be open-ended, whereby I would ask a general question, such as a description of their experiences in the doctoral programme, and my participants would be free to discuss any issues relevant to them, but I ended up carrying out semi-structured interviews. Opening up an interview with a question with a very wide focus and no particular end in sight did not work in this study, and I found, instead, that my participants would address a small part vaguely and then wait for me to ask another question. I quickly adopted an interview style based on a narrative because 1) I had to make an on-the-spot decision about which questions to ask to guide my participants, 2) formal education is a series of chronological events in a person’s life, 3) a semi-structured interview guide in chronological order helped as an organising principle when it came to data analysis, like a ‘formatting’ of interviews. A copy of the interview guide is included in appendix B showing the major areas of questioning and prompts for myself.

In practice, this led me to ask about the participants’ prior educational or professional experiences and their motivations for undertaking their PhD programme. This would be followed by asking questions such as: “It is your first day on the PhD programme, what do you do, how do you get started?”
What happens during these first few months?”. The discussion would then move onto levels of support available during the PhD and the types of knowledge and skills the students thought they were gaining. Invariably, at this stage, issues of identity and belonging (or not) to specific groups would be discussed. This stage allowed insights to be gained into the more relational side of the programme and the students’ relationships with peers, supervisors, Management, laboratories and other groups of individuals. The next set of questions would examine their experiences on the work placements if already carried out or their expectations of the placement if planned. I was interested to find out about their experiences in general but also how they viewed their skills (and their usefulness) in the transition from PhD to workplace. This type of questions brought up the perceived or imagined differences between a career in academia or in non-academic settings. One of the last steps covered in my questions was the participants’ thoughts about their future careers to try and grasp the effect of the PhD programme and the work placement on their thoughts, expectations and preferences. Finally, I closed the interviews by asking if there were any issues the participants thought I should focus on in my research and whether they had other views they wished to discuss. The interviews took place in private meeting rooms and lasted between one hour and one hour and a half, were audio-recorded and transcribed in full.

As mentioned earlier, interviews were not a priority in my research design, which was much more based on informal interviews, the topic of the next section.
4.5.4 Informal discussions and oral accounts

In ethnographic studies, informal interviews, or what Atkinson (2007, p.99) refers to as ‘unsolicited interviews’, are considered useful sources of evidence and information. Oral accounts are part of everyday life as participants share news with each other in what is considered a naturalistic setting (ibid.) and are part of the practices that humans engage in when interacting with each other. Because of their informal character, oral accounts and informal interviews were found to be more spontaneous than face-to-face interviews, which can sometimes feel like interrogations (Flick, 2009, p.169). In face-to-face interviews, participants were more reliant on waiting for me to ask questions and ‘lead’ the conversation, although interviews were presented as ‘open interviews’ (see section 4.5.3 above). Overall, I found informal accounts to be highly relevant because participants are free to talk at length, on their own terms and spontaneously. Moreover, although informal accounts cannot erase the influence of the researcher, they can certainly minimise the effect (Atkinson, 2007, p.101). Informal discussions and oral accounts, due to their spontaneous nature, lasted from just one minute to about twenty minutes, depending on the situation, how many students were present and the topic of the conversation. They took place in all academic settings described above (lectures, presentations, etc.) and were noted down after the interaction.
<table>
<thead>
<tr>
<th>Data Source</th>
<th>Description</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus group</td>
<td>1 Group of 6 students</td>
<td>Collect data for MRes/QAA conference and start formulating a topic of interest.</td>
</tr>
<tr>
<td>Interviews</td>
<td>2 x supervisors 2 x experienced interdisciplinary researchers 6 x students</td>
<td>Gather perspectives on early developed themes of the study from students. Access information from established researchers. In-depth understanding of students’ perspectives. Triangulation exercise.</td>
</tr>
<tr>
<td>Observation</td>
<td>Business courses: 8hr Project presentations: 20hr Induction sessions for new students (x2): 12hr Summer School 2019: 2.5 days Advisory board meeting: 6hr Oral presentations on work placements</td>
<td>Build researcher background understanding and relationship with students. Information on students’ communication and presentation styles. Hear feedback from staff. Information on how the programme is explained to students, along with expectations. Participate in summer school activities with different interdisciplinary CDTs. Annual CDT review with external comments and feedback + student presentations. x12 students. Understand students’ experiences of the placement.</td>
</tr>
<tr>
<td>Informal conversations</td>
<td>Based myself in OPTIMA office at QMRI: 6 months OPTIMA management Public engagement officers Students</td>
<td>Meet other CDT students in optical imaging, observe relationships, interactions and activities. Feedback and study on work placements. Immerse myself in and participate in students’ everyday life.</td>
</tr>
<tr>
<td>Grey literature</td>
<td>CDT-OPTIMA JeS application CDT-OPTIMA website and blogs Government and institutional documents</td>
<td>Discussions with various informants interested in/experienced in interdisciplinarity. Find out the aims and visions of the CDT. Blogs from students’ perspectives and website for further background on CDT. Understand the UK Higher Education policies.</td>
</tr>
</tbody>
</table>

*Figure 9: Description of data collection methods and purposes*
4.6 Grey literature

The grey literature was drawn from official online documents: governmental reports, educational policies, university statements and strategies, and CDT-OPTIMA’s webpages. Organisational documents are often overlooked in ethnographic research yet have been found to provide rich data (Aavik, 2019; Grant, 2018, p.123) and, as Jasanoff (2015b, p.27) noted, policy documents can be mined for insights into the framing of desirable futures they seek to implement. In agreement with Freeman and Maybin (2011), I consider documents as artefacts that not only convey messages but also have a social role in organisations and institutions through the formulation and implementation of processes. The inclusion of documents alongside ethnographic methods of data collection allows for the widening of understanding (Grant, 2018, p.103) of the phenomenon under study by bringing the perspectives of different stakeholders (Patton, 2015, p.663; Ritchie et al., 2014, p.383). In the case of CDT-OPTIMA, documents enable an understanding of how various stakeholders consolidate their multiple interests through what was agreed upon and how actions can be coordinated around a shared project (Freeman and Maybin, 2011). In times of confinement due to Covid-19 restrictions, data collection through documents was also experienced by the author as a safe way of working (online research) and an opportunity to adapt to the challenges of doing research in such circumstances. The analysis of the documents rests primarily on the lens of the future and how it is envisioned and created by various stakeholders and can be found in chapter 6. As a Covid-19 mitigation
undertaking, chapter 6 is unequally balanced with the other two empirical chapters of this thesis and remains shorter in length.

The present study is based on online searches from the UK Government's website and the research councils (UKRI) to find relevant policy documents for doctoral education, skills, employability and interdisciplinarity (or collaborations). Around thirty strategic documents were scrutinised for their contents to investigate the purposes and values that underpin and guide the policies and the key elements they seek to implement as a framework (Cardno, 2019) to understand the rationale behind the UK educational agenda and the perceived value of interdisciplinary research training.

**4.7 Data analysis**

The following sections examine the data analysis processes of the research in detail, starting with a discussion on the iterative-inductive approach taken in the present study and the introduction of my own framework for data analysis through mapping.

My engagement with data analysis started early on in the project, during the master’s stage in 2018. At the time, I had decided to pilot a group interview with my participants in order to show explicitly how the process had informed my research design (discussed in section 4.5.1). It was not clear to me then just how much this early stage of data collection and analysis was going to steer the rest of my project and my analytical thoughts.

Learning through relationships and through participation in practices highlighted for me the need to consider the practice of PhD training and the
context in which these practices take place at the institutional, local and political levels. The relational aspect of interdisciplinary doctoral training grew from my engagement with participants and the data collected early in the project and remained a priority throughout the project. The complexity of producing a holistic view of my research while paying attention to the multiple relationships, contexts, and stakeholders’ interests led to a huge amount of further questioning of the data, followed by issues of data storage, retrieval, inventory, and other analytical challenges encountered during a qualitative research project, and as warned by Suter (2012, p.353).

The benefits of starting fieldwork early in the project and maintaining a prolonged presence with my participants allowed me to use the theme of relationships and to probe further into this and other ideas about certain directions, to illuminate patterns and to keep these thoughts in conversation with existing concepts and theories. For example, many CDT-OPTIMA students were heard during fieldwork comparing themselves to “normal PhD students” and how they saw themselves as being different. They saw their work, their PhD programme and their practices as not fitting with their conceptions of what a doctorate was and how it was embodied by their peers on traditional PhDs. I decided to work with the idea of a ‘gap’ as a sensitising concept to explore how and why my participants felt different to other students and also to try and understand if it was due to the interdisciplinary demands of their programmes. Issues of othering in interdisciplinary research have previously been explored (for example, most recently by Lindvig and Ulriksen, 2019) from the observations that interdisciplinary students often feel
somewhat different to mono-disciplinarians. By exploring the concept of a
gap, I interrogated this idea of difference, not as something that was
essentially there but to find out how it was produced, by whom, and for what
(if any) purpose. From a practice theoretical perspective, my data analysis
was focussed on interdisciplinary doctoral training in terms of the participants’
lived experiences and how they perceived their training in terms of
advantages and deficits.

The choice of method for data analysis in this research project is the result of
a rich and ongoing involvement and reflection with the data as it was
collected. I initially focussed on the themes that I identified as most important
for my participants, namely, learning relationships and life in academia,
before developing further themes. These were the most talked about topics
with and amongst my participants at all years of the programme and were
consistently talked about as matters of concern. Unsurprisingly, social
processes during the PhD understood as essential for learning so as to foster
relationships and communities to boost academic performance (Eyler, 2018,
pp.86-88), soon became an overarching theme for the students and the
study. The themes and their analysis will be developed in chapters 5, 6, and
7.

Relationships, interactions and interconnections are not always visible or
recognisable during data analysis processes using a Computer Aided
Qualitative Data Analysis Software (CAQDAS) like NVivo, excel
spreadsheets or other coding methods because of the complexity and the
volume of data involved (Saldaña, 2016, p.226). Other CAQDAS packages allow visualisation of relationships in the data, such as ATLAS.ti (eg. Friese, 2019, ch.7), but the formal structure of these packages and the time needed to learn how to use them were found to impede my attempts at data analysis, rather than facilitate them (further discussed in section 4.7.1).

The emergence of social processes as important topics for the participants drew me towards using complexity thinking as a tool for data analysis and was found to be also useful when looking at stakeholders’ interests in higher education. Learning as a social process is an equally important theme in the literature (Baker and Lattuca, 2010; Baker and Pifer, 2011; Eyler, 2018), and, as Lattuca (2002) argues, learning cannot be understood as separate from the context in which it takes place; learning is, therefore, a social, relational and situated process.

4.7.1 An iterative-inductive approach

My intended approach to data analysis was, first and foremost, an inductive method, which is at the heart of the grounded theory\(^{39}\), for example, as developed by Charmaz (2004). Whereas the original founders of the grounded theory, Glaser and Strauss (1967), advocated approaching the study of an area without any preconceived theory (Glaser and Strauss, 2017), the method has since been extended by other scholars, and the “term

itself has come to encompass a family of related approaches to research that reaches across many disciplines.” (Bryant, 2020, p.167). Upon experimenting with the grounded theory, I found it inevitable to keep moving between the empirical data and the theories present in the literature and decided to adopt, instead, an iterative-inductive approach as identified by O'Reilly (2012, p.30). This approach acknowledges that everyone starts out with preconceived ideas and theories and recognises the influence of the researcher in the research setting (O'Reilly, 2009, p.105). As an example, and apart from the act of preparing a research proposal (which implies a literature review of the topics), I had to make sense of some important concepts such as the doctorate, interdisciplinarity and the university. It was clear that my preconceptions and assumptions around these terms encompassed taken-for-granted understandings based on previous experiences, which obscured the very different meanings that can be assigned to them. From the perspective of practices, it allowed me to differentiate between definitions of these concepts and avoid thinking in terms of homogenous meanings.

Analytically, the iterative-inductive approach has meant moving back and forth between theory and analysis, data and interpretation. However, in practice, this method demands that a lot of attention is paid by the researcher to their use of theory so as not to shoehorn their data into their favourite methods and theories. As Timmermans and Tavory (2012, p.169) usefully advise: “we must be neither theoretical atheists nor avowed monotheists, but informed theoretical agnostics.”
I started coding my data and used NVivo as a tool for the facilitation of data storage, retrieval and linking. The use of CAQDAS in data analysis evolved to meet the requirements of researchers and what is sometimes seen as the tedious tasks and labor-intensive work of analysis (Patton, 2015, p.529). CAQDAS is used to assist the researcher in the process of data analysis and is often implicitly presented as ‘the way things are done’. However, while some scholars view CAQDAS as a ‘vital and indispensable tool’ (Saldaña, 2016, p.28), others argue that computer analysis can interfere with the analytic process (Patton, 2015, p.529). Most scholars writing on the coding of data suggest coding can be done either manually or through the use of CAQDAS, and the choice of approach is largely personal to a researcher’s preferences, computing abilities and the nature or size of the project (Basit, 2003; Tracy, 2013, p.184).

Many attempts at initial coding on different CAQDAS caused me great frustrations and disappointments because of what I now perceive as attempts to follow rigid methods in a rigid (computing) environment. I opted, instead, to use hand-drawn maps of my data. Maps allowed me to think through the themes I was generating from my data and explore how they interconnected with each other in complex relationships. This process was clearer and more useful for me because, firstly, it gave me the freedom to compare, analyse, reiterate and understand my data without oppressing my creativity. Secondly, my undergraduate degree from the Open University included a diploma in systems practice, which aimed to equip students with tools for thinking about and managing complexity. This diploma included thorough training in the use
of mapping, which has since become an instinctive way of learning and understanding.

NVivo and other CAQDAS offer an Explore function where users can create different maps to facilitate tasks such as analysing, determining, constructing, discovering and explaining\(^\text{40}\). However, I have always found the flexibility of manually drawing maps much superior to any computing programmes, mostly because they can be done anywhere in a matter of minutes, and they are easy to annotate, revise or aggregate, thus, convenient during fieldwork.

Mapping, in this case, based on a systems thinking approach to complexity, evolved after multiple readings of notes, documents, articles and transcripts of interviews and observations. While I mapped some of my thoughts prior to and during data collection, I had not anticipated using this method and therefore had to do a robust exercise of mapping my existing data systematically. This strategy was time-consuming because of the necessary re-reading involved but allowed for continuous involvement with the data and theories or concepts.

I found the mapping approach allowed me to carry out a highly reflexive process to my iterative-inductive method, as discussed above, based on Srivastava and Hopwood (2009) *practical iterative framework for data analysis*. As I organised my data in the form of maps, I started to develop common themes, which I was then able to aggregate together to understand

\(^{40}\) NVivo 11 help available online at: [http://help-nv11.qsrinternational.com/desktop/concepts/About_maps.htm](http://help-nv11.qsrinternational.com/desktop/concepts/About_maps.htm) [Accessed 05/07/2021]
either the connections between practices and relationships or to identify sites of tension. The themes were generated to address the research questions set out in section 1.2.3 from reoccurring patterns found across the participants in order to present a view of CDT-OPTIMA students’ experiences. The process is data-driven and akin to an inductive thematic analysis through mind-mapping, as discussed in Braun and Clarke (2006). The visualisation of data for qualitative research technique also offered the opportunity to think through the experiences of my participants through an empathy map. Empathy maps are normally used in business to understand the perspectives of individual customers but were also found to help medical students build empathic care skills (Cairns et al., 2021). For the present study, I constructed a map of the interdisciplinary student that represents the collective view of my participants (see figure 10), which allowed me to understand the perspectives of CDT-OPTIMA students together and to engage with the data analysis.
Figure 10: Model of the interdisciplinary student
Mapping for data analysis

The use of mapping in educational research is thought to have originated through the work of Novak et al. (1984) as a tool to help students learn and has been hugely extended since, especially through the work of Ahlberg and colleagues (for example, see: Ahlberg, 2004; Ahlberg, 2013; Wheeldon and Ählberg, 2012b; Wheeldon and Åhlberg, 2012a). Mapping has generally been promoted as a tool that allows students to represent complex relationships in diagrams (Davies, 2010) and to enable learning and understanding of teaching materials (Crowe and Sheppard, 2012). In qualitative research, concept mapping has been extended as a method for data collection and analysis (Braun and Clarke, 2006; Conceição et al., 2017; Given, 2008a).

In this study, mapping has been used as an approach to data analysis through the representation of meaning as diagrams. Visual methods can be an effective tool of analysis (Henderson and Segal, 2013), for example, when concept maps are used to interpret ideas (Vogt et al., 2014), but they can also be used for multiple purposes in research (Jankowska, 2014). This strategy can be challenging and requires extensive training of the user, but the relational approach to mapping, which connects concepts and themes, is considered one of the most versatile approaches (Conceição et al., 2017). Moreover, as O’Reilly (2012, pp.7-8) argues, the link between macro and micro perspectives is often lacking in empirical research, but relational mapping of data can bridge these perspectives by linking individuals’ practices to the wider context in which they take place. Furthermore, a visual
approach to data analysis is a form of simplified representation which allows the user to successfully navigate complex networks of interrelated ideas (Cooper and Zimmerman, 2020).

**Data analysis framework**

Research designs are frequently presented in the form of maps in handbooks that are mainly addressed to students (e.g. Blaikie and Priest, 2010, p.33; O'Gorman and MacIntosh, 2015, p.51) and usually appear in the form of a menu from which to choose the most appropriate methods. Moreover, data analysis methods and thematic analysis are barely disclosed explicitly in the existing literature (Attride-Stirling, 2001; Braun and Clarke, 2006).

Consequently, this section aims to provide clarity on the steps I followed for the present study, showing a highly iterative process that is itself nested in the overall research design, the project and the environment. Figure 11 is also an example of visualisation of data in the form of a map I drew to represent the data analysis framework I used, which is further described in detail.
Although the framework is designed to be used with several entry points to data analysis, each step is assigned a number in the diagram for ease of describing the processes involved in more detail. However, as indicated in

Figure 11: Diagram of a proposed iterative data analysis framework

~ 171 ~
the diagram, steps were carried out iteratively. During the whole process, I kept in mind my research questions and objectives.

**Step 1:**

This step involved multiple readings of data. *Reading*, in this case, was inclusive of several types of approaches (skimming, intensive) to becoming familiar with the data collected and also included typing and reading transcripts and is normally done in several stages. For example, the first reading may be focused on a general understanding of the information, the second reading may be used for in-depth understanding, and further reading may be needed to annotate the data, identify possible themes (common or contradictory) across participants, as well as trying to make a first connection with theoretical concepts.

**Step 2:**

Step 2 is designed to consolidate possible emerging themes or categories from the data and compare or contrast across multiple perspectives (individuals), levels of analysis (micro to macro) and possible useful concepts. I found it useful to draw these themes on separate notes and to keep a summary of these themes, to indicate which documents they can be found in and to interrogate the literature to identify any relevant data.

At this stage, I started to compare the themes and categories found in the data with the research questions formulated so far. This process is useful to identify 1) if the data collected begins to answer identified questions, 2) what
kind of data is missing, and 3) reflect on whether the research questions could be further refined or amended. It is slightly early in the process to make these choices, so good note-keeping about such reflections is essential.

**Step 3:**

In step 3, I carried out the data analysis through an iterative-inductive approach, as described earlier, which is a continuous and reflexive process of making sense of the data while keeping in mind some theoretical concepts. This step is a further iteration of steps 1 and 2 above, with the further purposeful aim of identifying the processes at work that seem important for the issue at hand and noting what is relevant to the research design.

**Step 4:**

Step 4 is the explicit mapping of each process, concept or theme that emerged previously. It probably includes further readings of the documents to ensure maps are as complete as possible with the relevant information. Again, I kept in mind the research questions when doing so and tried to map data in different ways and through different lenses. I mapped participant interviews individually and fully in the first instance, followed by further mapping, including other perspectives (individual, institutional, scholarly, governmental).
Step 5:

Step 5 is as creative a process as the previous step and requires a further reflection on what has been mapped so far. Maps can be completed (for example, adding theories at appropriate points), can be merged when themes are found to be similar, and in general, maps can be annotated with the author's reflections, questions and references to other relevant resources.

Step 6:

This step is a regular checking point where the researcher keeps in mind the quality of data collected, the analysis done so far and the research questions to ensure a watertight and thorough analysis.

All the steps above could be points of entry into the data analysis and, although numbered here for ease of description, rarely take place in isolation from each other. This framework is probably best suited for researchers who want to immerse themselves in their data and start the analysis at a reasonably early stage. Each step is iterative, reflexive, and the cycle is repeated multiple times. An example of mapping a portion of an interview is included below in figure 12, and a further example of mapping used in the data analysis is included in appendix C.
Figure 12: Example of interview mapping
Reproduced partially from one interview on the topic of working in the laboratories.
Participant’s words in black. My thoughts in colour.

4.8 Position of the researcher

In qualitative research, the researcher is one of the instruments of research (Simons, 2009, p.14) and relationships in the field are crucial to gather high-quality data (Webster et al., 2014, p.84). The researcher-as-instrument concept has many implications for the way data is collected, analysed and presented: for example, there can be tensions between strangeness and familiarity (Coffey, 1999, p.23).

As I was studying at the same university as my participants, my position may be viewed as an “insider” that presents both opportunities and challenges (Brannick and Coghlan, 2007; Trowler, 2016). Being familiar with the
institution and possessing special knowledge may have consequences for existing assumptions, biases and interests (Costley et al., 2010, p.3).

However, I also subscribe to the view that insiderness and outsiderness are part of a continuum, and there were many different times and situations during the project when I felt both, sometimes almost simultaneously, which is relatively commonplace in qualitative research and cannot be fully resolved and demands reflexivity (Acker, 2001) and self-reflection (Alvesson, 2003). Positioning myself (and being positioned by Management) as one of CDT-OPTIMA’s students greatly helped with issues of power because it placed me on equal terms with my participants, in contrast to studies performed by established scholars (also see, Da Wan, 2016). While I was very familiar with the University of Edinburgh, where I had been employed for almost fifteen years prior to commencing my postgraduate studies, I was unfamiliar with the locations in which I conducted my research, with the participants and with their field of study, which brought in the element of strangeness. Thus, even though my participants and I shared membership to the community of doctoral students, I was not a member of the same (scientific) community, which allowed me to ask for explanations when needed\textsuperscript{41}. Overall, my position as a PhD student researching other PhD students in the same university gave me many advantages over access to individuals, gatekeepers and spaces, although managing relationships with CDT-OPTIMA management and students brought important considerations.

As CDT-OPTIMA partly funded my scholarship, it was important to my supervisors and myself to be clear about my engagement with the project and to outline my position as a PhD researcher rather than as a consultant. Moreover, it was imperative that the CDT-OPTIMA management team (Management, hereafter) did not influence the direction or the results of this research in order to avoid biases and conflicts of interest (Laine, 2000, p.121), so we obtained a letter of understanding stating formally that Management would not influence this project (see appendix D).

My relationship with Management had to be managed and carefully balanced so the team would be comfortable providing valuable information on the PhD programme, their experiences with students, and for continued access to the field. At the same time, I had to be vigilant about not divulging any of my participants’ views during my discussions with Management to ensure smooth relationships with CDT-OPTIMA students, who may, otherwise, have positioned me as a management spy (Simmons, 2007). Inevitably, because of the management team’s continuous involvement with their students, individuals were already aware of many existing issues, which I could then discuss in more detail with them but withhold any information that could pose a threat to my participants’ anonymity.

I was keen to reassure my participants that I was not reporting any of our conversations to Management and that I was not in the position of a spy who would report on their activities, which was again emphasised when asking for consent. During fieldwork, many CDT-OPTIMA students who chose to
participate in the present study expressed their appreciation that I was studying their experiences and felt it was a good opportunity to voice their opinions.

4.9 Ethics

An ethical practice was followed to protect the research participants, myself and the reputation of our institution in accordance with the Research Ethics Framework of ESRC\textsuperscript{42}, the British Sociological Association\textsuperscript{43}, as well as institutional requirements. In this section, I discuss the ethical choices I made during the research after briefly discussing institutional ethical approval.

4.9.1 Institutional ethical approval

Level 1 approval from the Ethics Committee of the School of Social and Political Science has been in place since my first interaction with CDT-OPTIMA students during my master’s degree. Regular reviews of the consent and information forms were carried out and approved as necessary.

Consent form and information sheet are attached in appendices E and F respectively.

4.9.2 Ethics in practice

Educational ethnographers seek to build a strong rapport with their participants through immediate and practical activities, which warrants ethical

\textsuperscript{42} ESRC Research Ethics Framework, 2015, online at https://www.ukri.org/councils/esrc/guidance-for-applicants/research-ethics-guidance/framework-for-research-ethics/ [Last accessed 19/10/2022].

\textsuperscript{43} British Sociological Association Statement of Ethical Practice, 2017, online at https://www.britsoc.co.uk/ethics [Last accessed 19/10/2022].
behaviour during all interactions during the research project (Dennis, 2010). This type of ethical behaviour, as “ethics in practice” (Guillemin and Gillam, 2004, p.263), is related to but also distinct from institutional ethics. While the institutional ethics form guarantees anonymity and confidentiality, many informal discussions that happened in the fieldwork were carried out in the presence of peers. This example calls attention to the importance of not harming participants but also to be aware of one’s own ethical practice at all stages of the research, especially when the design is founded on trust, interactions and relationships. In these moments, it was my responsibility to make them aware of the presence of others and to invite the participant to move to a more discrete location. Lived in the moment and in the practice of research, “ethics are always practical” (Dennis, 2018, p.76), they involve quick thinking, and ethical situations are unpredictable. Fortunately, there were not many unforeseen practicalities during the fieldwork for this project.

Another consideration, early in the project, was the naming of CDT-OPTIMA in this thesis since it is usual in qualitative research to anonymise locations and institutions in order to prevent the identification of participants (Nespor, 2000). The CDT jointly funds my studentship, and my PhD position was widely advertised online; the information is, therefore, already available publicly, and I had to assume that readers could quickly identify my connection with CDT-OPTIMA. Therefore, I decided I could not offer my participants organisational anonymity even with the usual obscuring techniques available such as changing the name of my university (Trowler, 2016, p.43).
In line with Ezzy (2013), who offers the following advice for the respect of the other, I decided that obscuring my position or the institution would be deceptive and would break the principle of transparency.

Positionality - Research that claims to be objective and uninfluenced by the standpoint of the author is deceptive. Texts must recount the position from which the author speaks. (Ezzy, 2013, p.56).

Obscuring locations and places also has the effect of decoupling events from their geographical locations (Nespor, 2000), which may help the reader decide on issues of generalisability (section 4.10). Instead, I chose the names of Scottish rivers to anonymise my research so no individuals could identify the participants through identifiers such as gendered names. For similar purposes, I have chosen to use the singular “they” as a generic first-person pronoun, which is becoming more commonly used and thought to be more respectful and inclusive language44.

CDT-OPTIMA is a heterogenous community of researchers, staff and students, which may include disparate interests and goals. For anonymity reasons, I discuss CDT-OPTIMA as an entity when doing so involves quoting documents and webpages relating to the CDT in general. The CDT was formed through the partnership of several researchers (as principal investigators and co-investigators) who were all either interviewed or engaged in conversation during the research process, as well as observed during multiple meetings, presentations and other academic activities. When

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44 American Psychological Association, 2019, Welcome, singular “they”, online at [https://apastyle.apa.org/blog/singular-they](https://apastyle.apa.org/blog/singular-they) [Last accessed 19/10/2022].
it is necessary to quote a specific researcher within CDT-OPTIMA, I have used pseudonyms and refrained from quoting profile webpages, job titles or institutions and departments to maintain anonymity.

4.9.3 Ongoing ethical consent

In total, I obtained consent from thirty-two CDT-OPTIMA students who agreed to take part in the present study out of a total of sixty across all cohorts starting from the 2015 cohort. At the beginning of the project, I would distribute the information sheet and the consent form to participants during collective events such as presentations, inductions and meet-the-patient sessions. Participants were given as much time as they needed to read the forms and ask questions and were asked to sign the consent form with the explicit assurance that participation could be withdrawn at any stage of the research without any explanation. All students returned their consent. When students were interviewed or spoken to face-to-face, I repeated the process individually. A spreadsheet helped me track individuals who had already provided consent. Participants who consented previously were not re-consented in writing unless they engaged in further face-to-face participation. Some participants were re-consented verbally only.

During ethnographic observations, it is prudent to check that ethical consent is ongoing and that participants do not ‘forget’ they are in a situation of researched and researcher (Hammersley and Atkinson, 2007, p.210). On the other hand, it would be disruptive and unhelpful to issue participants with a ‘police caution’ style reminder (ibid.) that anything they say might be used for
research purposes, especially during participant observation. I made sure participants were reminded about my research project during my day-to-day interactions with them when they had already signed a consent form. I regularly checked they understood their rights to withdraw at any time during the study, on several occasions and verbally. It was my experience that participants were unlikely to forget that I was carrying out research with them, and reiterating consent often felt superfluous.

4.10 Critique of the research design

The methodology employed in this study aimed to provide a deep understanding of the participants’ experiences of their interdisciplinary doctoral programme. The multiple methods employed during this educational ethnography offer a rich picture of my interpretation of students’ views, although the focus on one single setting (CDT-OPTIMA) may be seen as a limitation. The advent of the Covid pandemic and subsequent isolation requirements hindered my original intentions to research interdisciplinary doctoral students in different settings. However, the research design allowed me to be flexible and responsive to the environment by moving my attention to the policy side of doctoral training and the perceived need for interdisciplinarity.

While this study did not strive to present generalisable findings, it is hoped that this thesis provides enough detail and empirical evidence so that the findings can transfer to other situations. This applicability beyond the confines of the research can be tested during the project through
extrapolation, which Patton (2015, p.713) describes as “modest speculations on the likely applicability of findings to other situations under similar, but not identical conditions”. These speculations were discussed during presentations and conversations with early career and experienced academics working across disciplines in different countries who found insights from this research applied to their experiences. The fact that individuals not involved in the research judge it relevant to their own situations is a process that Merriam and Tisdell (2016, p.256) call “reader or user generalizability”. Nevertheless, such generalisability (or lack of it) could be examined through further empirical research.

Chapter 4 discussed the use of educational ethnographic multi-methods chosen for the present study in order to produce and analyse data to answer the research questions set in section 1.2.3. Section 4.7 presented a detailed framework for data analysis using the mapping technique, which is seldom encountered in the existing literature on qualitative data analysis. The position of the researcher as a student researching her own institution was discussed in section 4.8 before turning to issues of ethics in section 4.9. The chapter concluded with a critique of the research design. The following three chapters present the empirical data gathered during the study and their analysis.
Chapter 5  Memories of the future

5.1 Introduction

This chapter examines students’ expectations and motivations for undertaking an interdisciplinary doctoral programme in CDT-OPTIMA. By asking students to recall how they envisaged their futures at a certain point in time, the discussion argues that educational choices, especially at the doctoral level, are mostly driven by imagined futures. Just as the sociology of expectations (Borup et al., 2006) is concerned with the future role of technological innovation, I argue in this chapter that educational policies are based on the role of expectations in training a workforce for the so-called knowledge economy and, hence, is concerned with scientific practices of the future. This phenomenon is a further example of the dominance of what Adam and Groves (2007, p.195) called “empty futures”. Empty futures relate to the idea that the future is purely pre-determined by its relationship to the present and eclipses notions of change, possibilities, and new opportunities. The present discussion relates to how current research policies and practices empty futures in a way that eclipses the essential unknowability of the future (Poli, 2017, p.59) through an examination of everyday future-making practices (Adam, 2011). While this chapter is mainly concerned with the students’ perspectives on their futures, chapter 6 will examine how the future is created through educational and research practices and policies.

5.2 Possible selves in the future

“The future is increasingly a realm of sociological analysis.” (Beckert and Suckert, 2021, p.1)
Beckert and Suckert (2021), quoted above, argue that although sociological research on the perceptions of the future has grown moderately in the last three decades, sociology still mostly orients itself towards the past and the present. Only recently, there seems to be a small but renewed engagement with time in the sociology of education (for example, see Lingard and Thompson, 2017) and research into higher education (Bennett and Burke, 2017; Brooks et al., 2022; Gibbs et al., 2014). This chapter explores how students prepare themselves for life after graduation and their expectations for their potential employability levels and careers through the lens of futures and possible selves. The notion of “possible selves” was introduced by Markus and Nurius (1986) and represents individuals’ ideas about what they would like to become, what they are afraid of becoming and, in particular for students, links motivation and imagination to identity formation (Markus, 2005). An orientation to the future is not about making predictions; rather, it aims to help understand how present practices are informed by visions of possible or preferred futures.

Learning, as conceptualised in practice theory, is always situated in practices and also anticipates future practices (Kemmis et al., 2017, p.51). This is because doctoral students partly make educational choices based on self-knowledge and how they see themselves in the future, an orientation to the concept of possible selves. From its psychological origins (e.g. Dunkel and Kerpelman, 2005), the concept of possible selves entered educational studies to provide a framework for understanding educational possibilities and learners’ expectations of their educational choices (Rossiter, 2007). In
the context of this study, students’ possible selves is understood through the lens of practice theory and refers to what students do in order to reach their vision of what they want to become in the future through imaginaries and their academic achievements, as discussed in Leondari (2007). When undertaking a PhD, students produce a thesis, but the product of their education is the development of themselves (Roberts, 2007). Principally used in studies from the perspectives of mature students (e.g. Stevenson and Clegg, 2013) or equitable access to higher education (Harrison, 2018), I identified the concept of possible selves as applicable to doctoral students whose choice of doctoral degree emphasises future expectations of employability and of a professional identity. Moreover, considering students in graduate education as adults has been found to be fruitful in previous studies (for example, see Heaney and Ramdeholl, 2015, p.7) as doctoral study is conducted at the nexus of intersecting power relationships (Brookfield, 2015, p.22) that students must navigate, such as academic hierarchies, finding their voices and becoming professionals. The future is orienting students’ present practices through how they think of possibilities, and the future is also being made by present practices. From this perspective, and following Mische (2009) and Beckert and Suckert (2021), it is essential to examine the “effects of a projected future as a dynamic force undergirding social change” (Mische, 2009). That is, as students imagine their futures and decide to undertake interdisciplinary doctoral training, they effect social changes that enable the reproduction of interdisciplinarity and, thus, re-imagine what a doctoral degree and universities are for. Previous
studies that have explored students’ motivations for undertaking higher education studies have compared young and mature students’ motivations as in McCune et al. (2010) but remain silent on how students imagine their futures and whether and how this influences educational choices.

As far as interdisciplinary research and training are concerned, a focus on past and present experiences has produced a vast amount of literature in interdisciplinary and educational studies where students’ motivations and expectations are mostly absent. In this literature, interdisciplinarity is often discussed in terms of its conceptualisations and the merit or disadvantage it may confer. Examples abound but can be found in Allen (2017) and MacKinnon et al. (2013) as two distinctive representatives of some debates within the current interdisciplinary doctoral training literature. Allen (2017) found that interdisciplinarity is an ideological driver in science education policy aimed at serving capitalist market interest. While interdisciplinarity has been shown to be marketed as superior knowledge by universities, as opposed to traditional research (Pizarro Milian and Missaghian, 2019), this perspective looks at promotional strategies of universities but fails to examine why there is student demand for such doctoral programmes, which is the main theme of this chapter. MacKinnon et al. (2013), on the other hand, found that interdisciplinary programmes should complement discipline-based programmes at the earliest time of undergraduate level. This conclusion may seem quite straightforward at first sight but obscures the fact that some students may be drawn to interdisciplinary research while others are not. This amounts to claims that interdisciplinarity is “good” for everyone and it should
not be an option but mandatory in education. Collaborative skills gained from doctoral training are seen as crucial in the current economic climate of many countries (Germain-Alamartine, 2018) and are strongly associated with interdisciplinarity. This view is also evident in the Economic and Social Research Council (ESRC) which has identified in its recent review (Tazzyman et al., 2021, pp.7, 31) the need to train students collaboratively and across disciplines to ensure they obtain the skills needed for a future job.

The existing literature on interdisciplinary doctoral education and how it is viewed or experienced by students is limited (Dooling et al., 2017, p.573). However, previous studies have been valuable for the insights produced, many of which have come to form practical recommendations for future programmes (Graybill et al., 2006) and guidance for students (Dooling et al., 2017). Yet, the practicalities of thinking about the future (Adam, 2011) are very rarely discussed. Graybill et al. (2006) assert that “an IDRT [interdisciplinary] program will neither define your future path nor get you a job…” and students should therefore plan their route ahead. Graybill et al., referring to future academic careers, fail to recognise in the above quote that a future path in academia is often predicated on disciplinary specialisation (section 2.1.3). Similarly, Dooling et al. (2017, p.582) advocate the need to negotiate the “best” career path for oneself. In the absence of a knowable future, planning and negotiating a career path could be said to belong to the

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45 The link between interdisciplinarity and collaborative work is discussed in section 2.2.
46 The literature drawn on here is intentionally co-authored by Graybill, Dooling, Shankas in 2006 (with others) and in 2017. It is one of few studies of interdisciplinary doctoral students’ experiences drawn from their actual educational journeys. The lapse of time between the two publications doesn’t indicate any evidence of engagement with possible futures.
realm of reading the future and risk comparing students to prophets (Adam and Groves, 2007, p.17). Planning and negotiating a career is only possible in the presence of hopes and desires about a knowable future (Adam and Groves, 2007, p.31), which shifts the responsibility to students themselves. Students are informed individuals, and their orientation to the future is also based on the current practices that underpin the research landscape but may be influenced by the universities’ marketing of interdisciplinary programmes (discussed in section 6.5).

It is clear through my engagement in this research project that doctoral students experience the field of possibilities and expectations (the future) as they choose to undertake their doctoral programme. The future-oriented practices of education are not only visible in the ways in which participants imagine their futures but also in how universities market their doctoral programmes and which type of doctoral research and training is currently prioritised and funded by the UK Government.

5.3 The motivation for interdisciplinary learning

My findings indicate that CDT-OPTIMA student population typically possess a disciplinary background in either life or physical sciences (for example, biology, chemistry, or physics). The UK educational system allows early disciplinary specialisation (Griffin et al., 2005b), which seems to be a feature of many other countries, where “the professionalization of academics at national level in most European countries operates so as to reinforce monodisciplinization” (Griffin et al., 2005a, p.4).
The present study found the common motivation for the participants to undertake their doctoral programme is primarily based on the desire to learn something new and towards choices for their potential employability levels after graduation. The drive to learn was visible in the field during sessions such as the grand challenge, placement presentation and meet-the-patients sessions. The issue of expanding and widening knowledge is illustrated in the following quote:

I was a (disciplinary identity) by trade […] but I had quite intense projects and I had the feeling I know quite a lot about (disciplinary technique) and if I stay in this place, I won’t learn much more during my PhD and I want to learn something new (Coe).

For this respondent, learning more about a technique or a specific discipline does not represent learning something new, and there is a sense that the PhD is expected to bring about new experiences. The motivation for widening their knowledge bases and encountering new experiences points to one way students imagine their futures, in which they are concerned about deep disciplinary knowledge as being limiting. This is explicit in Tweed’s comments: “I didn’t really want to do a conventional PhD where I would just be limiting myself to being in a lab after the PhD”. This participant then goes on to discuss how they saw the advert for the CDT-OPTIMA doctoral programme and found it very different from other programmes: the key attractant for Tweed, thus, was the learning of other skills that could be used in different careers.
There is a sense, then, that disciplinary specialisation is something that is limiting and stands in the way of learning something new. A deep specialisation is viewed negatively from the outset and is not seen by the students as a goal to strive for. Quite the opposite, students talked of broadening their horizons and being unconstrained by disciplines, like Spey, for example, who said they did not want to do (this discipline) for the sake of it but instead wanted to use their existing knowledge and skills to “make stuff and then use it.” Thus, there is an expectation common across the participants in this study, which invokes the practicality of skills and knowledge. Sometimes these expectations are emphasised by family and friends who comment that a student might find a cure for an illness and that “it would be a huge event” (Forth). Other students spoke of the practicality of learning in terms of developing their scientific skills for their future careers (Leven).

Because CDT-OPTIMA students are interested in learning outside their primary discipline, it could suggest that they are pre-disposed to work in an interdisciplinary manner. This would reinforce the idea that individual traits of students and researchers are important factors for interdisciplinary work, such as flexibility, willingness to learn and creativity (Lyall et al., 2011b, pp.33-35). The participants showed they possessed these traits by choosing to study across traditional disciplines or wanting to enlarge their knowledge. It remains to be seen whether these pre-dispositions are necessary for interdisciplinary research or whether they can be learned. In their report to the National Science Foundation, Gamse et al. (2013) identified six core
competencies for conducting interdisciplinary research and discussed how certain activities could help students develop these skills. However, they make it clear that their findings cannot tell whether participation in certain activities causes individuals to become strong interdisciplinary scientists (Gamse et al., 2013, p.4, original emphasis). This implies that individuals may choose interdisciplinary education because of an orientation towards breadth of knowledge and that recruiters for such interdisciplinary programmes should pay close attention to the personal characteristics of applicants.

My own study found that when students develop a view that disciplines are limiting for their futures, they clearly signal two different and, maybe, seemingly contradictory points of view. On the one hand, they hold expectations for a possible future that should contain as many opportunities as possible so as not to be limiting, as Spey remarked, “I want to keep my options open”. However, and explicit in the existing interdisciplinary literature, choosing an interdisciplinary path may actually close off future alternatives because of the disciplinary structure of universities (section 2.1).

According to the lens of the possible selves, present practices serve to achieve a like-to-be self or evade a like-to-avoid self (Harrison, 2018) compatible with a vision of the self in future states. These practices, or discourses, reveal the students’ expectations towards what they feel is (currently) the best way to orient themselves to their futures but can only be a matter of temporality until a future state has been achieved. Bertrand de
Jouvenel's (cited in Poli, 2017) distinction between facta and futura is helpful here in understanding the temporality of students’ being. The future is neither real nor imagined (Øverland, 2013), and like students' trajectories, it is in the making between what is already known (facta) and what is imagined or not yet achieved (futura). In this CDT-OPTIMA study, students’ motivations for undertaking an interdisciplinary programme are best understood in terms of temporality and reaffirm that what individuals do in the present partly produces their futures (Bennett and Burke, 2017). However, students’ trajectories through life are not necessarily linear, and the notion of temporality allows for the idea of the nomad (Tait, 1999). Students can be said to be nomads as they return and revisit their understanding of their practices and the way they build their futures (Clegg, 2010). The idea of the nomad is implicit in the educational and career trajectories of some of the students in CDT-OPTIMA and is best exemplified by Ettrick, who took time off education after their undergraduate degree, completed a placement in industry and then being unsure about leaving academia decided they wanted to study for a PhD. Currently, students are advised to specialise in a discipline before embarking on an interdisciplinary career (British Academy, 2016), but the futura contains many possibilities. For example, universities and policies are prone to fashions (Czarniawska, 2014) and young scholars should exercise caution with notions of interdisciplinarity and mounting interests that promote it (Goodwin, 2006).
5.4 The promises of interdisciplinarity

Students' negative views of disciplinary specialisation and preference for broader educational experiences are not the only factors at play when choosing an interdisciplinary programme. The prioritisation of Science, Technology, Engineering and Mathematics (STEM) disciplines in UK policy since the Roberts’ review (Roberts, 2002) continues to be seen as a way to achieve economic growth and a skilled workforce (National Audit Office, 2018, p.5). The focus on STEM at all levels of UK education (Skilling, 2020) is thought to encourage new approaches to solving complex problems and is, thus, involved in the push for interdisciplinarity (Holley, 2019). Moreover, graduates with STEM skills are often thought to enjoy higher earnings than those from other disciplines, as attested in the Wakeham review of *STEM degree provision and graduate employability* (Wakeham, 2016, p.13), making doctoral research in STEM a particularly valorised experience (Kelly, 2017, p.51).

Although it is thought that students are not planning their careers from the start of their doctoral training (Wellcome Trust, 2013, p.13), there is much evidence from this study to show that the possible self is already in competition with others in a job market, which may or may not exist in the future. There is a strong association between interdisciplinarity, the types of skills students wish to acquire, and their translation into a commodified future. Here, I quote two participants who epitomise the idea of expected returns in their futures:
How am I going to get an advantage over them [my pals]...with my science background as well. (Spey)

You realise that if you still want to progress in industry, you need a PhD...The people who didn’t have a PhD didn’t seem to get very far. (Fyne)

A commodified future is a type of present future based on the idea that it represents an economic resource (Adam and Groves, 2007, p.193). Treating a degree, such as a PhD, as a positional good holds implications for social mobility and inequalities, matters of great concern in the UK (Bukodi et al., 2015), but unfortunately, outside the scope of this project. Instead, I wish to discuss the doctorate through the idea of competition in the present future. As already discussed in section 5.2, participants in this study see interdisciplinary research as a way to broaden their horizons and gain wider skills that would not otherwise be possible to achieve through disciplinary specialisation. CDT-OPTIMA students are aware of the many skills they acquire during their training, from “speaking different languages” (Leven), to thinking differently from other students (Tweed) and even doing something interesting (Coe). The idea that such skills and rewards translate into some capital to be used at a later date would only hold if the future was taken to be already present and known rather than still to be enacted. Thus, the future and education are commodified and economised at the expense of other educational goals such as developing responsible citizens and facilitating their development (Brooks et al., 2022, p.93). This insight is further reinforced through students’ interactions, as commented on by Fyne, who was told by a friend: “It seems harder to find a job for the people who are not in a CDT.” According to findings from this study, not all doctorates are equal in terms of
providing opportunities for the future, and this may explain, partially the
growth in student demand for different types of PhDs, such as
interdisciplinary, professional or strongly vocational-oriented training. This
study also finds that the future value of a doctorate is an important aspect
both within and outside of universities. Like any other resource, a doctorate
can be seen and valued from different perspectives. In academia and current
governmental rhetoric, particular disciplines, such as STEM, are highly
valued (Kelly, 2017, p.51), whereas employers are looking for students who
are ready to work and may value vocational and professional doctorates
more strongly (Higgs, 2019). It is, therefore, unsurprising that CDT-OPTIMA
students put so much emphasis on their experiences during the mandatory
work placement in industry, usually in the third year of the four-year
programme (discussed in section 7.2.6). Yet, as discussed earlier, there is no
direct causal relationship between a present work placement and the level of
employability of a student in the future.

I will argue in section 8.5 that the commodification of the future is a specific
feature of governmental policies for research and the evaluation of research.
That students think in those terms is evidence of the strength of the political
rhetoric and debates around the doctorate and how they are actively
engaged in the (re-)making of universities. Although CDT-OPTIMA students
are passionate about their research, such as Coe, who said they like the idea
of having an interdisciplinary background and the students’ motivation
discussed in section 5.2, future employment is firmly and unsurprisingly at
the forefront of their educational choices. However, universities increasingly
concentrate on employability figures (Higgs, 2019) based on policy discourse regarding the requirements for highly skilled workers for the labour market. Unfortunately, the job market is not increasing to accommodate the supply of new graduates (Brown et al., 2004). In this perspective, interdisciplinary doctoral training becomes explicitly linked with economic gains (Pizarro Milian and Missaghian, 2019); education is increasingly conceptualised through an economics lens (Shavit and Park, 2016) and students are progressively seen as economic resources (Brooks et al., 2022, p.93). Interdisciplinarity, thus, becomes more than a way to produce integrated knowledge across disciplines but also acts as a political instrument that produces exaggerated expectations (Graff, 2016). As a political instrument, the interdisciplinary label is applied to many doctoral programmes (and undergraduate studies) purely for the purpose of building an Education UK brand (Lomer et al., 2018) with a view to positioning the country as a science superpower without consideration of the future of graduates (further discussed in section 6.4.3).

The next section examines the relationship between the science part of the doctoral training and expectations from the MSc business, innovation and entrepreneurship to discuss the concept of expected future rewards.

5.5 Expected future rewards

Section 5.2 discussed how an interdisciplinary mode of research is conceived in opposition to the limiting effects of disciplinary specialisation, at least as one possible self in the temporality of the student phase. Section 5.3
examined the value of a doctorate in the job market and practices of commodifying the future. The next step in remembering the future is to look closely at the expected future rewards of obtaining an interdisciplinary PhD. This time, the focus is not on gaining an advantage in a competitive job market, although it is, of course, a major issue, as discussed in the previous section (5.3). Instead, I wish to examine expected future rewards through the students’ perspectives of what they stood to gain by studying for a master’s degree in business and entrepreneurship alongside the scientific research programme.

I do feel that doing this CDT will improve my employability as I will come out with a diverse set of skills that other CDTs do not provide. (Orchy)

Orchy’s comments are vague about the way in which undertaking a PhD in CDT-OPTIMA might lead to better employment chances than other CDTs. Because most CDTs are funded to solve scientific problems, they almost invariably involve an interdisciplinary mode of research (see section 3.3). CDT-OPTIMA is different from other CDTs in that it is a doctoral programme with integrated studies. The portion of integrated studies is delivered by the University of Edinburgh Business School, alongside the first three years of scientific research, as the fourth year is normally considered as the writing-up stage of the thesis. Based on my informal discussions with CDT-OPTIMA staff and students and participation in some business courses, I understand the business training is delivered as a suite of core and optional courses in healthcare innovation and entrepreneurship that together make up an MSc (Business MSc hereafter). Although the MSc modules are assessed, and
students need to reach the minimum pass mark, the MSc is not awarded as a separate postgraduate taught master’s and is only a part of the PhD with integrated studies programme (section 1.3.2).

CDT-OPTIMA students are overall in agreement when it comes to their early perspectives on the Business MSc. Students found the idea of the MSc interesting, and it “came along [with the PhD]” reports the most enthusiastic of students who relays becoming really excited about the innovation side of the programme but “only because of the advert for the PhD” (Forth). Forth further explained they had not had any prior exposure to knowledge on life sciences start-ups and ventures but, after finding out more on the subject, with a view to gaining entry on the CDT-OPTIMA PhD programme, found it appealing. The same participant offers an explanation that “it’s stuff you’ve never seen before, you never hear about that kind of person who is so freakishly ambitious.” This explanation might not fit every student’s view on innovation and entrepreneurship but is reasonable given the traditional UK early disciplinary specialisation in schools and undergraduate studies (discussed in section 4.2) and probably a lack of experience in this domain. More importantly, the two participants quoted here reflect the general view that the Business MSc is an add-on to the doctoral training rather than a motivation for it or a process that makes the doctoral programme interdisciplinary. Whereas students orient themselves to the future when they talk against a disciplinary specialisation and how the PhD can be conceived as commodifying the future, there is no discussion of such future orientation when discussing the business, innovation and entrepreneurship components.
as perceived at the start of the programme, although this can change in some individuals towards the end of their studies. In fact, there is a strong division between the PhD science work and the MSc business courses in the students’ rhetorical practices that remained obscured to me for several months until participants were asked for clarification through interviews and informal conversations. For the students, science is the PhD and encompasses all the skills and learning that mostly happens in the laboratories (where science is practised). On the other hand, when students refer to OPTIMA, they do not refer to their research. The term OPTIMA, as used by the participants in this study, is purely used to describe experiences that are relevant to the Business MSc or to identify the CDT’s management team. This small insight was highly informative for two reasons:

1) It confronted me, as a researcher, with my own expectations of what I was investigating (PhD or OPTIMA, or both?) and put me in a position to appreciate the difficulty in communicating with people outside my own field.

2) Students’ choice to talk of their PhD and OPTIMA experiences separately is a subtle but perceptible sign that the division of labour in universities along disciplinary lines is still alive and well, even in a community thought to be interdisciplinary.

From this discussion and the evidence gathered from participants, it is difficult to say whether the Business MSc part of the PhD programme is
sought after at all, at least when exploring students’ motivations to apply for the programme.

As I reflect with hindsight, the business courses do not figure prominently in students’ orientation to the future and their possible selves. As discussed previously, a minority of students became particularly interested in the entrepreneurship element of the taught courses, but even their expectations were quite low, noting that it was “just in case” they might use the skills, obviously a second choice. Rather than driving students’ possible futures, the business courses arguably represent an element of academic capital. Here, Marginson (2002), who analysed the enterprise university as a political formation, provides a probable explanation. The rhetoric of business and innovation is that of the government, whose approach to the knowledge economy is to fund programmes that will produce the future science entrepreneurs. This specific view of education is also supported by academics who have been involved with spin-offs during their careers at the university. For example, one of the founders of CDT-OPTIMA claims they have been pioneering research at the chemical-biomedical interface for almost 20 years and have a number of patents and spin-out companies to their name.

For some students, the credentialling function of the university is more important than the course content. Whereas students are aware of the potential benefits of obtaining a doctorate and are motivated to expand their knowledge, becoming an entrepreneur is not at the forefront of their
concerns, even for the most enthusiastic students. Coe offers a pragmatic explanation:

If you’re very academia driven then OPTIMA is not the right programme for you. You need to be a bit interested in business. But then, on the other hand, if you’re only interested in the business stuff, then OPTIMA is also not a good choice (Coe).

This shows the difficulty for interdisciplinary students to think of their possible selves along two very different career pathways. One pathway is the science, the other is business, innovation and entrepreneurship. From this perspective, challenges remain in how to produce the desired science entrepreneurs who will make UK Plc a science superpower through interdisciplinarity as a political instrument.

The following section focuses on specific imaginaries which, in the present study, were found to have a strong presence among the CDT-OPTIMA student population.

5.6 Doctoral training and imaginaries

With an emphasis on applied science for translation of research into innovation and the mandatory work placement, CDT-OPTIMA doctoral training aims to produce graduates ready for work inside as well as outside academia who are able to integrate knowledge across disciplines and with exposure to real-life problems and collaboration skills (Thune, 2010). Most CDT-OPTIMA students who participated in this study wrestle between contemplating a future career in academia or industry. Socialised through their study programme at the highest level of education, students in this study
are ambivalent about their futures. They are confronted with choices they
mostly perceive as a dichotomy between the prestige of academic research
and the financial rewards of a career in industry, finding themselves unable to
reconcile both sides or to make sense of the tensions they perceive between
both sectors.

This section suggests the new conceptualisation of the doctorate emphasises
some old issues around the PhD, which, far from having been addressed, are
actually being amplified. Namely, the politicisation of the UK doctorate is
rhetorically, at least, reinforcing the notion of a gap between academia and
industry by seeking to bridge it through the marketisation of an imaginary.
This imaginary is present in the aspiration of students in their hope of a
competitive advantage in the labour market and a political ideology of
economic growth for the good of society and implies a re-definition of
universities’ roles and missions in social life. CDT-OPTIMA markets itself as
a highly innovative PhD programme that will revolutionise modern healthcare
through interdisciplinary research, which is thought to be the future of
science, as explained by Tay during my fieldwork. The view that
interdisciplinary knowledge is more relevant to societal issues is a direct
product of the impact agenda of government policies that press for utilitarian
education for economic growth (Maton and Christie, 2013, p.4). This
perspective opens up several questions regarding the use of
interdisciplinarity in research training, quality of academic research and the
future of Higher Education. Except for the resulting competition between
universities to offer doctoral programmes for a flexible and ready workforce,
there is, so far, no evidence that interdisciplinary doctorates produce better
life chances in the job market for two reasons. Firstly, in academia, a career
path is dependent on being a specialist or an expert in one discipline (British
Academy, 2016, p.9), and universities produce more graduates than they can
employ and are not always supportive of interdisciplinarity (Holley, 2018).
Secondly, careers in industry are not dependent on a basic or applied
distinction (Agarwal and Ohyama, 2013) but on the capitalisation of
competencies by students, market factors and other complex social factors
such as age, gender and cultural background (Monteiro et al., 2022).
Moreover, EPSRC has identified that non-academic employers may lack
awareness of the benefits of employing doctoral graduates (EPSRC, 2021,
p.54).
It is clear that UK universities work towards annual targets of students’ start-
up businesses\textsuperscript{47} and, in so doing, align themselves with government policies
to advance the agenda of added value of Higher Education\textsuperscript{48} with the view to
marketing these results to potential students as a proxy for quality of
research. There is also some evidence that new PhD programmes are being
marketed to develop a brand for UK higher education to create a demand
from international students through the promise that a UK educational degree
will confer advantages in the job market (further discussed in section 6.4.3).
Using the concept of “social imaginaries” (Taylor, 2004, ch.2), I will focus on
the CDT-OPTIMA doctorate as a product of government and policy rhetoric

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\textsuperscript{47} Personal email communication from Shiel, Edinburgh Innovations department on
19/10/2020.
\textsuperscript{48} \url{https://www.hesa.ac.uk/data-and-analysis/business-community/ip-and-startups} [Accessed
21/10/2020].
designed to fulfil wider market and commercial concerns, as opposed to treating scientific and academic knowledge as a social good. I critically assess the idea of why and how a gap seems to appear between the ideas of working in academia and the so-called “real world” and how this gap influences the way academia and industry are imagined along market lines. I argue in this thesis that by seeking to bridge such a gap, educational policies, through the reconceptualization of the doctorate, are, in fact (re-) creating the idea of a gap, which is best addressed through offering interdisciplinary research training to students. In this way, the intellectual output of academia is preserved through the accreditation of students with the highest degree in education while positioning students as major assets in the real world.

Following Taylor’s (2004, pp.24-29) definition, social imaginaries represent, in a general sense, the expectations and common understandings individuals hold about social life. However, these are “unstructured and inarticulate understandings of our whole situation, [… and of] unlimited and indefinite nature.” Imaginaries are socially negotiated, and both inform and are informed by social practices, which individuals adopt, resist or are inducted into. In this sense, the PhD imaginary is a relational product, which emphasises the way people are in relation to each other and expectations around the benefits that can be derived from the obtention of the qualification (Kelly, 2017, p.4). The flexibility of the concept of social imaginaries, as defined by Taylor (2004), acknowledges that understandings of what universities are for, are multiple, negotiated and also unlimited in nature.
Thus, it allows creative thinking when reflecting on the status of universities and higher education in social life.

Participants in this research display strong imaginaries about what a PhD is and what it means for a working life in academia compared, whether favourably or unfavourably, with the imaginaries of a working life in industry – or what is considered in everyday terms as the real world. These imaginaries are the basis for the students’ evaluation of the future profitability of their education and affect students’ practices and decisions. The real world⁴⁹ is the world out there as contrasted with the world inside the ivory tower.

Shapin (2012) made the point that the metaphor of the “ivory tower” has been used to criticise universities and their practices. Talking about the ivory tower nowadays is a derisive reference to a particular way of understanding universities and the work that takes place therein, but the ivory tower itself, Shapin argues, never existed. The metaphor figuratively accentuates what some people deem to be wrong with academia, namely that one should get out of the tower into civic reality and that universities should be responsive to the world around them (Shapin, 2012).

Following Björck and Johansson (2018) and Björck (2018), academia embodies the relationships and activities of the environment where students are trained in theory and is commonly referred to as the university. The

university is where disciplinary knowledge is transmitted to students (Choy and Delahaye, 2011) as opposed to the real world, where theory is put to practice and acquired knowledge is applied (Björck, 2018). The metaphor of the real world is one frequently used in academic literature (Alvesson and Spicer, 2010; Gray, 2004), in media (Kirchherr, 2018), and during casual conversations (Orr, 2002). However, the term is mostly used implicitly, without further definition, and its meaning, at least throughout the UK, is taken for granted. The real world, as disconnected from academia, is thus a form of discourse that is present in everyday life and, as will be demonstrated below, is also present in how students perceive the workplace. Very few studies, with the exception of Björck (2018), have attempted to deconstruct what is meant by the real world and the implications of using this metaphor. Here, I draw on the metaphor of the real world as a device in the context of doctoral training in order to examine its significance for and relationship to interdisciplinary research and training, and to show how the metaphor helps students construct imaginaries about workplaces.

The world of work as the real world is epitomised by Tweed, who was grateful for the opportunity to go on a work placement as it was “an opportunity to actually go and see what it’s like in a real environment”, as opposed to learning on business courses and “it was a whole different world.” However, it is clear that boundaries between these two worlds are more elusive and not as fixed as the common understanding of them supposes.
The analysis of the data reveals tensions between imaginaries connected to academic and real-world careers, especially in the context of competition and the advantages or inconveniences of different paths. Garnok exemplified the idea of competition in the job market outside academia and commented that individuals have to market themselves hard. The idea of competition for positions in academia is strongly reinforced by the induction of new students, which I observed several times during fieldwork, and many CDT-OPTIMA students quoted fairly low percentages on their chances to obtain a position in a university. Forth also commented that academic careers are unstable, while Tweed felt “you have studied for like a decade of your life, you shouldn’t be in a position where you need to worry about grant funding every three or four years”. Overall, CDT-OPTIMA students had strong ideas about what a future in academia or industry would entail, but these ideas were in constant evolution and changed over time, especially after their mandatory work placement. The pursuit of an interdisciplinary doctorate, irrespective of what motivated it at first, induced strong feelings of uncertainty from the participants about their possible futures, and many participants talked about indecision over whether they would like to stay in academia or not; something Forth called “flip-flopping” between the two ideas. By far, the biggest obstacle to academic careers mentioned by CDT-OPTIMA students is publishing and its importance in metrics for career progression. Coe, like many of their peers, felt negative about future prospects in academia based on the unending requirement to produce publications. Students who participated in this study were very aware of the need to publish and saw it as a crucial
requirement for academic positions. These students, therefore, seem to
privilege publications as an indicator of their worth rather than the quality and
creativity of their research, no doubt influenced by their peers and
supervisors and related to impact requirements from the REF exercise
(section 3.5). A recent study of doctoral students’ perception of the
imperative to publish (Horta and Li, 2022) showed how it affects every aspect
of identity trajectory development by overemphasising publishing over other
academic activities, creating stress and causing students to work extra time.
While it is true that competition is fierce for academic careers, section 7.2.4
will highlight why it is particularly so for interdisciplinary students who feel
othered and may lack a professional identity.

5.7 The doctorate as a positional good

Through the themes of possible selves and the future, this chapter explored
the motivations of CDT-OPTIMA students for their choice of doctoral training
programme. The above discussion highlights a view of the doctorate as a
positional good, which may confer some advantages but also reinforces the
idea of competition in the job market. A positional good, according to Shavit
and Park (2016), is said to be positional “if its relative value is negatively
determined by its use by others”. In other words, the PhD is a positional good
when it remains relatively scarce in the population and is perceived to confer
advantages in a competitive world of work. CDT-OPTIMA students become
aware of the many skills and abilities they develop through their training (see
chapter 7), but their choices and discourses are nevertheless greatly
influenced by the market rhetoric that underpins UK policies (see chapter 6).
The focus on education as a positional good exaggerates and sustains the concept of student as consumer, as imagined by the UK Government (section 3.7), leading to hyper-competition and a re-configuration of the role of universities in social life.

Interdisciplinarity is marketed to support the UK Plc and Education UK brands and encourages university metrics underpinned by levels of employability of students. It is used as a strategy to attract more students who expect better jobs as interdisciplinarity is often talked about in terms of superiority that provides students advantages in the labour market (Pizarro Milian and Missaghian, 2019). However, the concept of the future emphasises that students are selves in the making with infinite options of possible selves and who are asked to know what they are still to learn (Marginson, 2002). While they are informed about the world in which they live, their choices and current practices are based on an illusionary concept of the future, which may or may never happen. Political forces steer doctoral students in their choices towards applied, interdisciplinary programmes which are couched in terms of intensified positional competition (Brooks et al., 2022, p.101) in an already congested labour market that accentuates inequalities in society (Brown, 2013). This perspective would lead to questions of sustainable growth in interdisciplinarity if it were to become the norm in academia. As Alberts et al. (2014) have warned, in the USA, the over-valuing of translational research is creating a hyper-competitive environment where fundamental research is eclipsed by short-term goals, publishing is increasingly more difficult and time-consuming, and the
academic job market is fast changing. This environment is thought to be harmful to early career researchers as they aim to prove the worth of their work and plan their future careers (Fochler et al., 2016).
Chapter 6  Creating futures

Chapter 5 examined how CDT-OPTIMA students chose to undertake an interdisciplinary doctoral training programme by orienting themselves to the future by means of expectations. However, the research and development (R&D) landscape includes a myriad of other stakeholders (such as government, research councils, industry) with different interests in and engagement levels with scientific knowledge. These stakeholders also use expectations and promises as future-oriented practices to create shared visions, enact change, and construct different educational practices that come in tension but co-exist with more traditional academic practices. The present study will show (section 6.5) that the practices among the stakeholders are interconnected and mutually constitutive or co-produced through the perceived role of scientific knowledge in visions of futures.

This chapter is concerned with how government and their research councils and universities interact together around shared projects and disseminate novel practices throughout the system. The exemplar of interdisciplinary research and training used in this study shows how the R&D system can become more or less stabilised through the use of common visions, expectations and promises about the future, which are then deployed to extend and institutionalise different modes of research.

Universities and government’s orientation to the future is discussed in sections 6.1 and 6.2, respectively. This future is also animated by the
concepts of curiosity and creativity, which are often used in descriptions of interdisciplinarity in politics and the interdisciplinary literature (section 6.3). The following section turns to the analysis of the grey literature, which highlights how future-oriented practices are embedded within different levels of the research and development system by presenting the views from the government (section 6.4.1), the views from CDT-OPTIMA (section 6.4.2) and those from universities (section 6.4.3). Section 6.5 ends the chapter by discussing the concept of sociotechnical imaginaries (Jasanoff, 2015b) and expectations to show how institutions in the triple helix (discussed in section 6.5) create specific visions for the future.

### 6.1 Universities and the future

The Edinburgh Futures Institute is for the inventive, the critical, and the creative. We are for those who embrace new ways of thinking and want an education that helps shape a better future, for themselves and for our world. (The University of Edinburgh Futures Institute).

As epitomised in the above quote, universities create possible futures for society by building on past knowledge, taking responsibility for their current practices, and for the making of their own future (Facer and Wei, 2021, p.203) and that of society. Facer and Wei (2021, p.193) argue universities are faced with “temporal ambiguity”; the struggle to work with the past, care for the future, and learn from the present. These temporal demands on universities are creating conflicting ideas of relevance and accountability of academic practices: retaining scientific authority and expertise over academic

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50 Edinburgh Futures Institute website, online at [https://efi.ed.ac.uk/education/](https://efi.ed.ac.uk/education/) [Last accessed 22/11/2022].
knowledge, working to help solve complex problems and anticipating future contexts for the use of knowledge. As pointed out by Facer (2018), academic practices have a consequence and an influence on the wider world by choosing which (and whose) futures are significant, which futures to work on, and on whose behalf to act.

Universities rely on their academics to produce new knowledge and to teach students within a wider UK R&D landscape that includes funders, national research and educational policies, research infrastructure, industry, charities and many more. I argue in this chapter that governmental stakeholders and universities engage in the production of sociotechnical imaginaries (STIs), as defined by Jasanoff (2015b, p.4). Fundamentally, STIs perform as collective visions of social life, which call on specific scientific projects and associated technology to enact a desirable future and positive visions of social progress (ibid.). These future visions entail new practices and understandings of how research and training are conceptualised and rely on their wider transmission from universities to students. In the case of this study, I will show that interdisciplinary research and training, premised on the development of new products or services, is based on such STIs where the future of the world is predominantly imagined as relying on healthcare innovations and innovators.

The governance of research and education is increasingly calling for interdisciplinary practices as a mode of knowledge production, thereby re-framing the research agenda of universities based on promises and expectations of future visions. These futures are highly value-laden and
deeply embedded in the political cultures of the country and, therefore, involved in the re-affirmation of dominant national identities (Jasanoff, 2015a, p.335).

6.2 Politics of future-making

The governance of science has long been a preoccupation of governments worldwide, especially since the aftermath of World War II and the recognition of scientific contributions to military efforts (Ash, 2019; Jasanoff, 2015a, p.324). In the last two decades, higher education and its governance have become even more pressing issues in the UK (e.g. Ball, 2015), reflecting concerns around limited funding resources, research priorities, global competition, and expectations of societal benefit. The increasing pressure on universities to adopt the goals, structures and procedures of corporations (Collini, 2017, p.16) for the UK’s economic growth has led Collini (2017, p.133) to compare universities to businesses that need to compete on the global market and to describe higher education institutions under the umbrella of HiEdBiz Plc. Unambiguously, the practices and policies of government involve difficult decisions about the future, including the production of relevant knowledge and the training of future knowledge workers (Wenger et al., 2020, pp.9-10). With the responsibility of “managing” the future in mind, the government and its agencies engage with higher education institutions as the main sites of knowledge production, as well as a variety of stakeholders that together form what I refer to in this study as the UK Research and Development (R&D) landscape.
The government and research councils see scientific knowledge as a strategic resource to be used efficiently to create wealth and improve the quality of life of UK citizens (Martin and Johnston, 1999). This is particularly true of the life sciences and associated biomedical sciences, biomedicine and biomedical technology (“life sciences” or “biomed”), with their reported turnover of £80.7bn in the UK for 2019 (Office for Life Sciences, 2020, p.4). As one of the dominant economic sectors of the UK, the life sciences drive much of the UK’s visions and strategies for future growth and employment (Bell, 2017). During the 1993 UK Technology Foresight Programme, the life sciences sector was already identified as scoring highly on both wealth creation and quality of life (Georghiou, 1996), therefore making the sector highly exploitable (Martin and Johnston, 1999) and a prime area of interest at the intersection of politics and academia (Wenger et al., 2020, p.4). This entanglement of scientific knowledge and politics underpins imaginaries of “innovation-driven progress” and how to achieve it (Aarden et al., 2021; Jasanoff, 2015a, p.333). The UK Government’s rhetoric on future-oriented knowledge will be the focus of section 6.4.1.

CDT-OPTIMA, as a direct result of specific funding policies (section 1.3.2), can be understood as an instrument in the government’s attempt to create futures based on life sciences and innovations. However, as I will show in section 6.4.2, CDT-OPTIMA is not simply a passive entity that exists within a university, but it is a network of scientists and individuals that helps translate the government’s imaginaries from the political to the academic sphere and, further, to the social sphere of students. As such, CDT-OPTIMA plays an
important role in promoting a shared vision of the future, in shaping interdisciplinary educational practices and in the process of institutionalising interdisciplinarity within the university.

6.3 Curiosity, creativity and research practices
The concept of curiosity has traditionally been applied to the idea of the autonomous researcher who carries out pure research, driven solely by the advancement of knowledge and free from the pressures of the state and the market (section 3.1). But curiosity drives humans’ imagination and leads them to strive for a (better) future and to produce innovations (Nowotny, 2008), and thus, is deployed in science and education policies that seek to promote interdisciplinarity while emphasising the freedom of researchers. UK policies present the image of a thriving researcher by continually tying science and curiosity as follows:

Research systems thrive on excellent research scientists who are strongly motivated most often by great curiosity and by the freedom to pursue their intellectual interests. (Nurse, 2015, p.3).

And then by interlinking curiosity with freedom in research:

[…] institutions in which researchers are free to follow their curiosity, to test radical new ideas, to tackle complex societal problems, and to form new connections, collaborations and networks. (UK Government, 2020, p.11).

Thus, the move from curiosity to interdisciplinary research is made seamlessly and attributed to individual researchers rather than to a political ideology. Similarly, interdisciplinarity is often associated with both creativity and curiosity in the existing literature (e.g. Lyall et al., 2011b, p.35; Szostak,
2017) and is emphasised in policies that stress the importance of collaborative projects and programmes to foster the creativity of researchers (UKRI, 2022). Walsh et al. (2013) point out that the concept of creativity is difficult to define but that, discursively, it is mainly used in two ways: “creativity as capital” embedded in the innovation and human capital pillars of the knowledge society and “creativity as performativity” for the impact agenda. A few scholars found evidence, though, that creativity that promotes independent thinking is frowned upon in universities where vested interests seek to protect the power structures of academia (Ángel Medina, 2006; Fava, 2005).

In addition to the two types of creativity proposed by Walsh et al. (2013), Darbellay (2015) and Darbellay et al. (2014) contend that interdisciplinarity requires a logic of “creative marginality” (from Dogan, 1990), which they define using the concept of nomadism (also discussed in section 5.2). That is, a disciplinary researcher can move around disciplines by means of borrowings, transfers and hybridisation of disciplinary techniques and methods to produce new knowledge. Darbellay et al. (2014) also note that while creativity clearly depends on individual competencies, the collaborative dimension of interdisciplinarity is fundamental in an era of internationalisation of research, and they argue that “interdisciplinarity, creativity, and collaboration are three keywords that will undoubtedly become increasingly inseparable” (ibid., p.8, original emphasis).
Nevertheless, the concept of “creativity for performativity” advanced by Walsh et al. (2013) cannot be ignored because institutions and researchers must take into account considerations of accountability (section 3.5) and show the relevance of their research to society. Thus, the concept of creativity in research and policy, which implies a level of freedom to pursue intellectual interests, comes in direct tension with research investments and governance that provide direction for the use of specific methods (i.e. interdisciplinarity) and ways in which doctoral students should be trained.

Essentially, policies that emphasise the curiosity and creativity of researchers seek to control the future by protecting against potential threats and stand in sharp contrast to desires of exploring the unknown (Nowotny, 2008, p.3).

### 6.4 Future-oriented practices

This section examines expectations from the perspectives of three key stakeholder groups: the UK Government, CDT-OPTIMA and universities. It is important to keep in mind that this discussion is premised on the specific funding model of CDT-OPTIMA as an interdisciplinary doctoral training centre in life sciences and a priority target for government funding at the time of the CDT grant application.

**6.4.1 The view from the government**

The UK Government includes an Office for Life Sciences whose remit is to “champion research, innovation and the use of technology to transform health and care service” (UK Government, 2021b). The work of the Office for Life Sciences is premised on the basis that:
The UK has the opportunity to become a science superpower, building on strong partnerships between universities and businesses, which can support a “Global Britain” vision, in particular in high-growth sectors such as aerospace, the creative industries, financial services, and in emerging industries such as AI and fintech. (UK Government, 2021a, p.6).

In other words, by leveraging the R&D activities of universities and businesses, high-growth sectors will benefit from strong technological innovations and will be able to create higher-wage jobs, leading to economic prosperity and the UK being recognised internationally as a science superpower. This perspective highlights the importance of universities’ research activities and their perceived role in developing technologies and innovations. In the above quote, the promises from scientific research are clear and are directed towards the UK’s international reputation, the UK’s economic growth and skilled jobs. It is worth noting, though, that this future only seems conceivable for high-growth sectors and remains silent about other sectors of the economy. This future also presumes that current high-growth sectors will remain so.

In this vision, individuals are essential and needed to build capacity for the relevant workforce of the future. Logically, if UK PLC is going to be a superpower, it needs individuals trained in “gold-standard settings” to ensure the continuous advancement of research and for “providing the future leaders for the UK economy”, as can be found in EPSRC’s 2014 document “Building skills for a prosperous nation - EPSRC Centres for Doctoral Training”. 
The major UK research councils (UKRI) work together “for an outstanding research and innovation system\textsuperscript{51} in the UK that gives everyone the opportunity to contribute and to benefit, enriching lives locally, nationally and internationally.” (UKRI, 2020). UKRI follows the Government’s “Research and Development Roadmap” (UK Government, 2020) closely in order to identify opportunities to support science, research and innovation across the UK. The UK research councils explicitly support the government’s vision of the nation as a science superpower with the specific aims of advancing knowledge for economic productivity and quality of life\textsuperscript{52}.

The UK Government and research councils regard the relationship between scientific knowledge and its translation into technologies as straightforward and part of the remit of universities. This vision can be rearticulated using the concept of the linear model of innovation. Godin (2006a) extended this concept noting the historical past of the framework and that it was mostly taken for granted and hardly ever documented. Briefly stated, the full linear model of innovation, in use since the 1950s, asserts that innovation stems from pure research to applied research, to development, production and diffusion processes (also see Godin, 2017). Otherwise stated, if the government invests in certain types of research and in certain fields, the scientific community will respond accordingly and produce both knowledge

\textsuperscript{51} Research and Innovation system is the rhetorical term used in some policy documents but also refers to what I have called the R&D landscape throughout the study. For the present research, the terms can be used interchangeably.

\textsuperscript{52} Research councils statements can be found online under Mission and Vision pages of their websites. For example, EPSRC https://epsrc.ukri.org/about/facts/mission/ [last accessed 19/10/2021] and BBSRC https://bbsrc.ukri.org/about/vision-mission-strategy/mission-history/ [last accessed 19/10/2021].
and innovations. Therefore, R&D investments will eventually lead to a prosperous future.

Vastly criticised over the years (Shaw, 2022; Tait and Williams, 1999), this simplified logic model seems to persist in the thinking of government and funders when funding scientific research. The model assumes that scientific knowledge can be translated into a positive economic impact. As such, the role of universities in society is redefined, and educational policies are bound to the service of the economy (Wolf et al., 2006). For example, in this study, the funding of CDT-OPTIMA demands that the host universities adapt their behaviour, structures and practices towards an interdisciplinary mode of working, which contrasts with the traditional disciplinary model of organisation, research and education (discussed in section 2.1.1).

The funding of CDT-OPTIMA, as discussed above, is expected to deliver key outputs in the form of “interdisciplinary scientists” as well as outcomes that are less well-defined such as future leaders for the UK economy or scientist entrepreneurs. How and what type of doctoral training is to be delivered at universities is therefore embedded within a socio-political discourse aimed at societal benefit through the commercialisation of innovative technologies and the levels of employability of future researchers, as described by Etzkowitz (2016). As will be argued in chapter 7, linking interdisciplinarity and translational research reinforces visions of the future.

The linear model discussed here is purposefully simplified but is nevertheless useful as a tool to highlight how the top-down decisions about research
funding are based on specific visions of the future (Britain as a superpower), expectations from scientific research (it will boost economic productivity) and the promise that all will benefit (citizens, industry, healthcare, graduates, among many others). In highlighting these features, the model suggests ways in which interdisciplinary research and training as a concept can also be used as a political instrument designed to distribute particular imaginaries about scientific research and enables the construction of stories of progress associated with innovations.

As discourses of futures and their visions are constantly articulated throughout educational and funding policies, they are also propagated further afield, communicating important messages to research funders, universities and researchers. This communal adoption transforms and perpetuates visions and expectations imaginaries (Jasanoff, 2015b, p.4), apparently yielding collective agreement around a joint project of future making. Once a collectively agreed upon way of working, interdisciplinary research and training become a new norm to strive for, a new object of research and a new way to engage with, or market, doctoral training. Embedded within this collective agreement are the assumptions underpinning the policies in the first place but now firmly offering an assimilated priority for scientific research rather than focusing on the political economy of knowledge (section 3.7). In other words, the UK R&D policies aim to harness scientific knowledge for economic productivity and well-being of society that will place the country in a position of superpower. For this vision of research governance to become collective, it must be seen to promise benefits to all stakeholders so the
endeavour can be undertaken through a shared understanding of what is to be achieved.

The next section examines CDT-OPTIMA and its founding researchers’ visions for its existence, what these visions involve and how they might relate to the visions of the government and funders discussed above.

6.4.2 The view from CDT-OPTIMA

While interdisciplinary doctoral training practices are local, complex, and interconnected, some features of CDT-OPTIMA are likely representative of other forms of interdisciplinary doctoral training in the UK and may, therefore, be of wider interest to the research community around this topic. Thus, this section examines the raison d’etre of CDT-OPTIMA and its visions for the future and the aims it sets out to achieve.

The R&D landscape is powerful in conceiving the future, not just as mere possibilities or representations but also in actual forms of future-making (Andersson and Kemp, 2021, p.6). One of these forms of future-making, for example, is the doctoral training delivered by CDT-OPTIMA that will:

Train the next generation of entrepreneurs with a Heart for Science and a Brain for Business ensuring that the UK has a strong and sustained pipeline of innovators and research leaders in the global sector of optical medical imaging.53

This quote is underpinned by several implications for current practices and is based on assumptions about the future. Namely, it is possible to predict the future to a certain degree (innovators in optical imaging will be needed), which implies that the next generation of entrepreneurs must be recruited and trained now. In this potential future, such graduates will be called upon to lead, be employed and innovate in the (potential) global sector of optical medical imaging. This logic is based on the linear theorisation of the relationship between learning-in-the-present and being-in-the-future (Amsler and Facer, 2017) while ignoring the global context of social, cultural, economic and environmental disruptions (Arvanitakis and Hornsby, 2016, p.7).

The logic between learning and the future - or preparing students for a predicted future - is said to be harmful in many respects as it promulgates a status quo regarding how to think about currently highly topical issues (for example, environmental sustainability and equality). Imagining the future and embedding practices into the present is a way of converting the imagined into solidity (Jasanoff, 2015a, p.323) and the perceived need to equip students with the tools and practices to enact this specific future. However, as Amsler and Facer (2017) argue, anticipatory regimes close off spaces of possibility for creativity in education and maintain the visions of futures “seeded in the logic of corporate consumer capital”.

Harmful outcomes vary in their scale of severity, from facing disappointments (van Lente, 2012), learning hopelessness (Amsler and Facer, 2017), or even
living in fear of artificial intelligence (Cox, 2021). These outcomes may be felt more strongly on an individual level (such as disappointments) but will eventually be felt across societies as they deal with disruptions in their governance of the future.

In the case of CDT-OPTIMA, promises of a better future abound in writing in all aspects of the centre, from the description of the programme, the grant proposal, and its website, as discussed earlier. I have observed new student inductions at the beginning of three academic years, and expectations are yet reinforced from the opening of the meeting when students are informed that they will be the next generation of scientific entrepreneurs in healthcare technologies. Other statements, such as telling students that translational science is about doing something useful, can become performative and affect students’ own understandings. Clearly, the formation of students rests on expectations and visions about the future, or at least desirable futures. Because these futures are politically imagined, and in the process of being materialised through scientific research, the students’ futures are already filled with hopes and fears of the political and academic context in which they are realised and can be thought of as “crowded territory” (Wenger et al., 2020, p.8).

The role of science and technology in these futures is crucial for establishing and ensuring the stability of the collective visions of progress, but it is also (re)produced and further embedded into cultures and institutions when seen to generate positive outcomes in the form of either economic or social
The embedding of ideas, materiality, values and sociality is what is known as a process of co-production in STS research, as strongly demonstrated in the work of Jasanoff (2004; 2015b; 2015a).

The mission of CDT-OPTIMA is tightly connected to the mission of the research councils (discussed in section 1.3.2) in addressing priority research, developing the next generation of innovators across disciplines, and to fast-track research from bench to bedside for the benefit of UK PLC. As is the case across the UK and elsewhere, grant proposals map onto the funder’s criteria and requirements (Evis, 2021). Without a doubt, funders play a major role in driving research efforts in UK universities through their choices and levels of investments (Lyall et al., 2013). However, CDT-OPTIMA is an active agent in extending government and research councils’ visions of interdisciplinary research and training, and its scientific community of scholars is at the centre of such practices.

The individual scientists responsible for creating CDT-OPTIMA describe their interests and motivations through the use of future visions. Talking about interdisciplinarity, Tay states that “interdisciplinary research is the future of science” and that “optical imaging will revolutionise modern healthcare…”. Annan focuses on the need to train the next generation of innovative scientists to ensure optical medical imaging continues to grow and benefit healthcare. Similarly, Torridon expresses a perceived need for the next

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54 Information gathered from CDT-OPTIMA’s funding proposal. Confidential document.
generation of young researchers for the rapid translation and application of scientific research.

During fieldwork, when I observed these scientists (like Torridon) introducing CDT-OPTIMA at student inductions or reading a description of their research interests, it was evident the scientists described what they thought might happen in the future and how their work would contribute to this particular future. Their arguments form the logic of the grant proposal, which itself is aligned with government and funders’ visions, as they address a specific call for funding, but they are based on an academic’s perspective of research and training and therefore focused much more on intellectual outcomes rather than economic aspects that drive the government. As indicated in the quotes above, these scientists are passionate about their research areas, the use of scientific findings for clinical use, and the training of students. The creation of CDT-OPTIMA is explained by the principal investigators during observation of inductions when it is made clear that the idea for such a doctoral centre is based on the scientists’ experiences of starting their own spin-off companies. Although such motivations can be understood as economic aims concerning careers, the data gathered from my empirical observations confirm that the scientists are firmly anchored in their research, laboratories, students, and academic roles in general.

6.4.3 The view from universities

CDT-OPTIMA is one of many interdisciplinary research centres located in one university. As educational practice is contingent and contextual (Ross,
this study cannot address issues of differences within and between different research institutions. However, the trend behind the exponential growth of interdisciplinary research and training is not a contested fact in the existing literature as scientific collaborations are becoming more mainstream, especially in the context of solving complex problems such as sustainability (e.g., Freeth and Caniglia, 2020), health (e.g., Little et al., 2017), and a variety of future challenges (e.g., Guimarães et al., 2019). Paradoxically, Evis (2021) shows that while Arts and Humanities Research Council (AHRC) claims its strong support for interdisciplinary research, budget allocations for this type of research remained extremely small in 2019. The further examination of eight universities’ strategic plans led Evis (2021) to observe that all universities noted interdisciplinary objectives in their plans and found figures to suggest that over half of all UK research output is derived from collaborations, which are presumed to be substantially interdisciplinary.

The signs that interdisciplinarity is growing on a global scale can also be found in studies of multi-author publications (Braun and Schubert, 2003), calls for collaborations from research councils and individual universities’ statements on institutional visions and support of interdisciplinarity. In its Strategy 2030, for example, the University of Edinburgh declares, “we will strive to make our research even more interdisciplinary and international, to address social and global challenges”. Some of this growth may be more rhetorical in nature rather than a significant growth of interdisciplinarity, and this point will be discussed in chapter 7. Universities UK (UUK), the
representative body of 140 UK universities, state on its website,\textsuperscript{55} “the success of UK higher education is built on a spirit of collaboration” and promote the view of universities as “economic engines”. Elsewhere\textsuperscript{56}, UUK explicitly supports the UK Government’s visions of research and innovation at universities and their role in supporting the economy, which felt to be of even greater importance following the Covid-19 pandemic and the anticipated need for economic and social recovery. As a voice for UK universities, UUK\textsuperscript{57} rearticulates the same visions as the government and research funders by highlighting the crucial role of universities as assets that will support:

The government aims to reinforce the UK’s position as a science and research superpower. We share these ambitions. Emphasising the strength of our research and development (R&D) will be vital to attract inward investment, continue making world leading discoveries, generate knowledge, and create innovative new businesses (p.2).

Universities in the UK and worldwide seem to unanimously and collectively extend the idea that interdisciplinary research and training are indispensable in a 21st-century education system. This perspective is evidenced in the publications from other organisations representing research-intensive universities: League of European Research Universities (LERU) in its position paper (Wernli \textit{et al.}, 2017), Universitas 21, Coimbra Group

\textsuperscript{55} Further information is available here \url{https://www.universitiesuk.ac.uk/about-us/introducing-uuk} [Las accessed 11/11/2021].
Universities and Russell Group who all embrace interdisciplinarity in education and research. However, as discussed in section 2.2, interdisciplinarity is a contested mode of knowledge production which is far from being embraced by all individual researchers.

Nevertheless, UK higher education institutions compete both nationally and internationally for research funds and to attract bright students from across the world for income (Brown and Carasso, 2013). In line with the government’s aspiration to create a national brand for UK higher education since the turn of the century (Lomer et al., 2018), universities have embraced marketing strategies to grow their reputation, the value of their courses, to demonstrate their economic competitiveness (Maringe and Gibbs, 2009), and to achieve good rankings (Gibbs, 2020). Thus, I would argue that it is also in the interests of HiEdBiz Plc (Collini, 2017, p.133) to market interdisciplinarity, for example as superior knowledge (to disciplinary specialisation) and for employability in the labour market, as was found to be the case in the Canadian university sector (Pizarro Milian and Missaghian, 2019). In this perspective, interdisciplinarity is instrumentalised and commodified by market-responsive service providers (universities) that focus on competition rather than on educative priorities (Gibbs, 2020, p.221). In this case, the utilitarian university (Rosso, 2019a) (also see section 3.7) can be seen to focus on a type of interdisciplinarity that is also utilitarian.
6.5 The production of the future in the triple helix

UK universities and scientific knowledge are firmly positioned in the economics paradigm of the triple helix. The triple helix concept, advanced by Etzkowitz (2018), is the relationship between state, industry and universities as they work together to translate research into use and places universities as important innovation actors. Whether universities are perceived as autonomous institutions facing aggressive state regulations (Tapper, 2007, p.234) or as market-oriented education providers (Dobbins and Knill, 2014, p.137), I have shown, through this study that the practices among the triple helix stakeholders are interconnected and mutually constitutive or co-produced through the perceived role of scientific knowledge in visions of futures. Governments and research councils hold high hopes for academic knowledge and how it can be harnessed to make Britain a superpower, both intellectually and economically and how it may benefit the whole population. Meanwhile, scientists at supportive universities, like those involved in this study of CDT-OPTIMA, are passionate about their field of research and the need for advancement and translation for clinical use.

The expected outcomes from interdisciplinary research vary slightly between the stakeholders but are not entirely in opposition and, in fact, show some complementarity in their goals. That is, technology and innovation predominantly derive from academic knowledge and will play an essential part in the future by engaging with society’s hopes and fears. This view is what Jasanoff (2015b, p.4) has called the co-production of sociotechnical
imaginaries, where science and technology and politics are interwoven and constitutive of each other.

In the case of CDT-OPTIMA, these sociotechnical imaginaries are based on political notions of futures that include better healthcare and historical ideas of a world-leading country (Britain superpower). The practices that enable such visions to be shared and endure are made explicit in the choice of knowledge production and transmission and involve interdisciplinary research and training.

As observed in this study, the motivations behind the creation of CDT-OPTIMA are clearly intellectual endeavours; even though, of course, scientists will also potentially benefit economically through advancement in career, reputation, and esteem. The UK Government and research councils are more prominently concerned with the role of scientific knowledge and its potential to make Britain a superpower and a prosperous society. However, as attested by the rise of interdisciplinary research and training worldwide, certain academic fields of study, such as the life sciences in the UK, are collectively held in high regard for the possibilities they may engender or the risks they may minimise in the future. Giving funding priority to specific fields exacerbates how disciplines compete with each other. For example, the biomedical sciences exert internal power and politics to make themselves worthy of funding by assuring they will deliver innovations. By association, the statement is value-laden for Humanities, Arts and Social Sciences (HASS), where disciplines tend to be considered as “inferior” or an add-on to
biomedical sciences – and where the research-policy gap is a major debate. Such a perspective overlooks the importance of the role of HASS disciplines in the development of innovation, especially in terms of responsible systems (Felt, 2014). The UK has also recently been the site of controversies and debates regarding the closure of university departments in History, for example, which has prompted major concerns over the loss of wide-ranging contributions traditionally made by this discipline. Moreover, the assumption of continuing growth in a field can lead to an unsustainable hypercompetitive environment that may suppress “the creativity, cooperation, risk-taking, and original thinking required to make fundamental discoveries” (Alberts et al., 2014) and risks producing too many graduates for the job market (discussed further in section 8.4.1).

The implication of the different visions and understanding of interdisciplinarity in academia and policymaking is the introduction of paradoxes. Organisational studies have shown the significance of studying paradoxes (e.g. Waldman et al., 2019), defined as contradictory elements that come into tension in organisational life (Putnam et al., 2016). Paradox theory shares an ontology with practice theory in that they reject dichotomies and focus on identifying dualities located in actors’ practices (Bednarek and Lê, 2017). An example of a paradox identified in this study is the political rhetoric used in policy to promote interdisciplinary research for technological advancement. This rhetoric permeates academia, for example, through funding calls, where

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58 For example, see statement from the Society of Antiquaries of London, online at https://www.sal.org.uk/2021/05/statement-regarding-the-threatened-closure-of-university-departments/ [Last accessed 18/12/2022].
CDT-OPTIMA promises to bridge the so-called bench-to-bedside gap through interdisciplinary research and training. The paradox is that while there is no single definition of what constitutes interdisciplinarity, it is repeatedly emphasised in universities and policies as the ideal solution to complex problems. The government’s linear perspective on interdisciplinarity as the driver for innovation (section 2.2.1) does not easily translate into academic practices that are primarily structured and organised by disciplines and consequently becomes problematic for universities and new researchers. Issues become evident for the reward and recognition of interdisciplinary researchers who struggle to demonstrate the value of their research through the REF (section 3.5), which may impede their academic career path and promotion (Lyall, 2019b, p.45). Another paradox introduced by the political agenda for interdisciplinarity has been discussed by Weingart (2000):

The more differentiation of knowledge production the more intense will be the call for interdisciplinarity (Weingart, 2000, p.30).

Interdisciplinarity (or transdisciplinarity and similar derivatives) is proclaimed, demanded, hailed, and written into funding programs, but at the same time specialization in science goes on unhampered (Weingart, 2000, p.26).

Thus, while the disciplinary specialisation of academic knowledge (section 2.3.1) has been seen as inadequate for solving complex problems, calls for interdisciplinarity seem to amplify this phenomenon, reasserting the crucial role of the disciplines in universities. This issue will be further discussed in section 8.3.1, which argues that the multiple-disciplinary field of medical optical imaging can be considered as a consolidating disciplinary field.
Overall, I argued in this chapter that the co-production of visions and promises among the triple helix stakeholders is based on a vision of the future, itself seeded in the logic of competition, that legitimises certain types of research and training that require an interdisciplinary mode of knowledge production. This perceived requirement for interdisciplinarity appears self-evident or natural as it seeks to suscitate researchers’ curiosity for outstanding research that presents itself as the solution for complex problems in specific fields, such as healthcare. In this manner, interdisciplinarity becomes a taken-for-granted concept that will lead to desired outcomes for the short-term future. However, these expected future outcomes eclipse the political goals and requirements that underpin the perceived need for interdisciplinarity and create paradoxes in universities and the work of scientists.

In this instance, expectations around the benefits of technical developments in optical imaging create specific collective agendas for new practices and requirements for their enactment (for example, see van Lente, 2012; van Lente and Rip, 2012). What this means in terms of practicalities for interdisciplinary research and training is the object of chapter 7.
Chapter 7   Interdisciplinary practices

[A] principle for the understanding of professions: if you wish to understand why professions develop as they do, study their nurseries… (Shulman, 2005, p.52, original emphasis)

While Science and Technology Studies (STS) have examined the work of scientists in-depth, STS scholars have only ever rarely scrutinised the practices involved in scientific training at the doctoral stage. The present study pays attention to the principle advanced by Shulman (2005) and considers CDT-OPTIMA as the “nursery” where scientists mature, hence an important site for examining interdisciplinary research and training.

7.1 Introduction

Previously, in chapter 5, I argued CDT-OPTIMA students actively sought interdisciplinarity as a mode of research training, as a political ideology has led them to believe that a future career will benefit from learning beyond one’s discipline. The concept of the future (or futures) is maintained throughout the chapter as a lens and placed centre-stage in the rhetoric concerning education, students’ expectations of their doctoral training and the use of imaginaries concerning possible futures.

Chapter 6 continued to develop the concept of the future to argue that UK educational policies are tightly connected with hopes and promises for economic growth and the image of Britain as a superpower. While UK research councils play a significant role in driving interdisciplinary research and training through specific and targeted funding calls, I considered the role
of universities and established scientists in reinforcing the perceived need for interdisciplinarity and their future-oriented perspectives.

So far, then, I have examined how interdisciplinary research and training seem to hold promises for a “better” political, social and scientific future. I also discussed the concept of futures in more detail to argue there is no clear, linear path between present practices and future outcomes. The future remains a sphere of possibilities that have not yet materialised and is always subject to multiple tensions and possible disruptions.

This chapter focuses on interdisciplinary research and training practices to examine the experiences of CDT-OPTIMA students and the difficulties they encounter during their doctoral programme. The following discussion adds rich details to ongoing debates regarding the nature of interdisciplinary research and how it is enacted in the context of the doctorate. The analysis shows a nuanced understanding of interdisciplinarity not commonly described in the literature. Interdisciplinary training, in this specific context, shares many common features with traditional doctoral training yet, also implies a host of hidden complexities. Section 7.2 introduces interdisciplinarity in the particular context of CDT-OPTIMA by examining the practices involved in training across academic disciplines (section 7.2.1), scientific professional training (section 7.2.2) and learning in complex environments (section 7.2.3). Section 7.2.4 examines what may constitute the space between disciplines before moving on to discuss relationships and
interactions in doctoral training (section 7.2.5) and, finally, the effect of the mandatory work placements (section 7.2.6).

7.2 Interdisciplinarity in the field

Section 2.2 highlighted that interdisciplinarity does not describe a single way of working. It has been researched in multiple ways, including its cognitive and social functions, possible ideal types of interdisciplinarity, and its connections to other modes of knowledge production. Far from representing a homogenous understanding among scholars and practitioners, the concept of interdisciplinarity is currently held as a promising mode of research. However, as argued later in this chapter, interdisciplinarity introduces disruptions to the practices of institutions of higher education, their staff and students.

Initially, it is also worth noting that in the case of CDT-OPTIMA, the concept of interdisciplinarity has different meanings, depending on the context in which it is discussed. For example, CDT-OPTIMA’s proposal to the research councils clearly states:

The interdisciplinary nature of the training (physical science, business and medicine), necessitates a cohort approach […]. And we will break down traditional ‘barriers’ between physical, medical, and clinical sciences, […]. This will create a new cadre of scientist who are [sic] multi-skilled […].

In this statement, the authors refer to students, in particular, who will train in cohorts to enable them to support and learn from each other and become a specific type of scientist.
In contrast, the CDT-OPTIMA Advisory Board Report of 2019 mentions in the research section that “Each project has, at its core, an interdisciplinary collaboration between PIs […] with a view to creating exciting interdisciplinary projects and fostering new cross-school, college and institution collaborations”. While interdisciplinarity is mentioned again, the focus has now shifted to the potential for interdisciplinary collaborations between established scientists.

Different uses of the term “interdisciplinary”, such as that discussed above, are often at the root of problems when trying to define the concept or during processes of creating shared understandings in collaborations (section 2.2). In this instance, it is unclear whether the project's emphasis is to produce a new generation of interdisciplinary scientists or boost interdisciplinary collaboration opportunities for existing researchers. While one aim does not preclude the other, in terms of management, expectations, and the mission of CDT-OPTIMA, these different aims need to be explicitly conveyed if they are to be addressed.

In order to circumvent this lack of clarity, I chose to consider interdisciplinary doctoral training through careful observations and consideration of the specific practices involved in working across disciplines in the context of CDT-OPTIMA. At first, this involves discussing the influence of academic disciplines on students' lived experiences.

59 Confidential document.
7.2.1 Research and training across disciplines

In a practice theoretical perspective, doctoral training, like all forms of learning, is primarily understood as participation in the practices of a specific community (Lattuca, 2002), especially with the aim of developing competency. In a traditional single discipline doctoral programme, students aim to gain membership into a community defined mainly by its disciplinary identity and particular practices. It is not to say that faculty members and students form a homogenous group as practitioners of specific disciplines. Students are trained in the epistemic practices of a discipline, and as previously observed, academic loyalties are generally highest to disciplinary affiliations than to institutions (Brennan et al., 2017, p.241).

When students embark on their doctoral training, they bring their own competencies and professional skills developed in earlier educational experiences or work experiences. These competencies usually involve single disciplinary skills and knowledge acquired through previous disciplinary education. Therefore, students bring with them previous skills gained through disciplinary “signature pedagogies” (Shulman, 2005) and “repertoires” (Holley, 2011), discussed in section 2.1.4.

As observed in CDT-OPTIMA, an intense period at the start of the doctoral training involves students acquainting themselves with different repertoires or ways of thinking (McCune and Hounsell, 2005). As argued by Schatzki (2017, p.27), learning includes how to perform doings and sayings, when to do so and, significantly in the context of the doctorate, how “these hang
together”. As Ettrick pointed out, “a PhD is a new experience anyway, no one knows how to do it when you start...”. While this is possibly true of all PhD programmes, the added difficulty in interdisciplinarity is to attempt to master different disciplinary knowledges, it is indeed “a steep learning curve” (Tweed). Moreover, doctoral training and its many practices take place in complex learning environments (Agustian and Seery, 2017), discussed in section 7.2.3. Thus, training to undertake interdisciplinary research requires learning and working with the repertoires, pedagogies and complex environments of multiple disciplines.

In single disciplinary research, practices form coherent bundles of practices (Shove et al., 2012b, p.81) because they co-exist and are co-located with the disciplinary organisation of universities and the disciplinary specialisation of many academics, lecturers and supervisors. Once mastered, these practices enable students to develop a deep understanding of the discipline. This deep understanding is not the simple acquisition or memorisation of knowledge from cognitive activities such as reading a handbook. Practising a discipline is knowing what to say and do and when and where to do so. Such disciplinary understanding entails what McCune and Hounsell (2005, p.257) termed “ways of thinking and practising” (WTP), which they describe as “the richness, depth and breadth of what students might learn through engagement with a given subject area in a specific context.” WTP is particularly salient in the context of interdisciplinary doctoral training because, as McCune and Hounsell further note:
WTP can potentially encompass anything that students learn which helps them to develop a sense of what it might mean to be part of a particular disciplinary community, whether or not they intend to join a given community in the future, for example, by pursuing a particular profession (McCune and Hounsell, 2005, p.257).

The importance of the WTP concept in the context of this study is its ability to connect disciplinary knowledge to disciplinary communities. Tweed articulates attempts at connecting with diverse communities and says it is about learning how to speak about research in different locations. Tweed perceives the difficulty mainly as a communication issue but is aware of the audience being addressed. The hurdle in this context is not knowing what to say (disciplinary knowledge) but how to talk about a disciplinary technique to a scientific audience from a different disciplinary community. Doctoral students who aim to acquire different disciplinary WTPs require extra efforts to be able first to identify diverse communities and, second, to attempt to gain membership into a particular community by adopting the correct WTPs. Tweed and many others in CDT-OPTIMA and the wider interdisciplinary community often describe this phenomenon as “speaking different languages.”

Furthermore, learning to belong to a disciplinary community also entails students learning about their changing identities (Barradell et al., 2018). Thus, interdisciplinary students are also subject to necessary identity work, which is constantly changing, depending on the context in which they enact their research. Interdisciplinary training presents issues in this context and brings about feelings of uncertainty for students. Almond – who stipulates
that science should not be defined by categories (disciplines) – explains, “I’m a scientist but couldn’t define what type…” . Because the training stage of scientists is essentially a socialisation into a (disciplinary) community (Boud and Lee, 2008, p.2), working and practising across academic disciplines is problematic for identity work. This issue is taken up in further detail in section 7.2.2 in the context of scientific professional status.

7.2.2 Scientific professional training

During the doctorate and in the context of the “nursery stage” of scientific research, the training of scientists can be understood as a professionalisation process in a scientific community (Serrano del Pozo and Kreber, 2015). Here professionalisation is used loosely to indicate the period of doctoral training at university leading to the acquisition of a recognised academic qualification, as per Eraut (2002, p.6). In this context, CDT-OPTIMA students are understood as training to become members of a profession – that of scientist. While acknowledging that such training and professional practices may take different forms in different places, training to become a scientist, in its most general form, allows an examination of the practices involved in the process, as opposed to a narrow focus on academic disciplines. At this stage, I also do not distinguish between university and profession-oriented knowledge, which is at the heart of many tensions and debates surrounding the professional preparation role of higher education (Eraut, 2002, p.8). Nevertheless, thinking about doctoral training as a professionalisation process provides a fruitful lens for understanding interdisciplinary aspects of research.
The concept of professionalisation can be conceived of as an issue of identity formation (White, 2002, p.3). From a practice theoretical perspective, identity formation is a dynamic and continuous process where people perform meaningful activities, including the skilled use of tools and resources (Beech et al., 2016, p.77). In the context of this study, interdisciplinary doctoral training is considered the professionalisation of students into scientists, and the appropriate “identity work” (Alvesson and Willmott, 2002; Watson, 2009) required to develop the legitimacy for carrying out the activities of scientific research (Beech et al., 2016, p.83).

Identity work and the idea of training to become a scientist have both been observed in this study as problematic processes for most CDT-OPTIMA students and were captured in many conversations through statements such as:

I felt like an oddball. I am a scientist, but I don’t know what type (Fyne).

I’m a jack-of-all-trades and a middleman (Solway).

Fyne and Solway’s comments, characteristic of many other CDT-OPTIMA students, were also expressed systematically in conversations between the author and other interdisciplinary doctoral students, reinforcing findings that interdisciplinarity is often “othered” (e.g. Lindvig and Ulriksen, 2019). Through their reflections, students show that the issues surrounding their professional roles are not due to a confusion about academic disciplines (which are not mentioned at all) but rather a confusion about how they can define who they are.
are professionally. Through such statements, interdisciplinary doctoral students reflect on their roles and on what they think they are.

Doctoral training traditionally reproduces the practices of which they are constituted, such as research, writing and defending a thesis. As such, CDT-OPTIMA is recognised (by scholars, universities, students, and funders) as an academic set of practices that leads to the obtention of a PhD by contributing to knowledge in a specific field. However, the participants’ quotes above show that interdisciplinary doctoral training leads to unstable professional identities at the early career stage. In contrast, when asked about their previous education, all participants defined themselves through their disciplinary training; for example, I am/was a chemist/engineer/biologist. Issues surrounding a sense of scholarly identity, or lack of it, have been shown to persist right through interdisciplinary scientists’ careers and have implications for their academic status (Lyall, 2019b, p.33).

While many theories of identity work exist (Beech et al., 2016, p.76), this study follows an understanding of social identities commonly applied in the management field. Identity work is a process whereby people continually strive to define themselves in different social contexts (Alvesson and Willmott, 2002). Thus, practising scientific identities during doctoral training can be thought of as a way to orient oneself to the future by rehearsing, constructing or simply trying out different versions of a future professional self. Such processes inevitably require interactions with other individuals because, in academia, scientific practices constitute communities, what they
deem acceptable, and how to act in and understand the world (Schyfter, 2013). Scientists form communities of practitioners who legitimate who can take part in certain activities (Beech et al., 2016, p.83) and sanction the level of competency of enacted practices (Schönbauer, 2017). The process of socialisation into a community of scientists is often concerned with the way students learn how to fit in the community over time through interaction with others (Austin, 2002). Interactions and relationships with others during doctoral training were identified in this study as recurrent themes, which form the object of the next section.

7.2.3 Complex learning environments

Working at the bench is a familiar expression for anyone training or trained in scientific research in a laboratory (also a lab, labs) as a fundamental aspect of socialisation in science practices (Delamont et al., 2000, p.175; Hofstein and Lunetta Vincent, 2003). As observed in this study, the bench is central to the practices of doctoral students in biomedical sciences. Agitation and heated conversations were witnessed during tours of the labs during CDT-OPTIMA’s induction days at both universities. Throughout their doctoral programme, students pointed to the importance of working in the labs in terms of scientific practices, relationships with peers, and learning, that were emotionally laden.

When discussing lab experiments, Forth comments the work may become “fanatically important” to some people who end up staying overnight in the lab to “see what the experiment will say.” For Ettrick and Coe, the lab is
where you learn by doing, or “where you do the training”. Many students mention feeling like intruders in the labs as they are the only individuals in the space working on a specific technique. Feeling like an intruder adds to isolation problems already common in doctoral programmes (Simons, 2005). Tweed reports that people in the lab “didn’t quite get what I was doing.” In other words, other students did not quite understand the OPTIMA project, which made it impossible to discuss their research with them. Leven eased this intruder feeling by becoming more sociable with lab peers, while Tweed ended up getting closer to other CDT-OPTIMA students. Tensions and anxiety are equally present in lab practices when students confront the uncertainty of scientific experiments and learn by “trial and error” (e.g. Forth) or must rely on peers and supervisors for guidance when possible. As summed up by Solway during fieldwork observations, “labs are where all the stuff happens; the exciting things and the tears.”

These wide-ranging responses to working at the bench reveal the complex character of scientific laboratories as sites of learning (Agustian and Seery, 2017). Laboratory work is only one of the technologies used in education, with many more available, especially at the doctoral training level, such as lectures, seminars, and conferences. These technologies of higher education are at once cultural, epistemic and social. They offer students the opportunity to learn how to act, think, and relate to others. In the case of CDT-OPTIMA, the complexities of grasping the practices relevant to the different technologies, whether in the lab or the lecture theatre, are in part reinforced
by the difficulty in reconciling different practices from various “signature pedagogies”.

Coined by Shulman (2005), signature pedagogies form “habits of the mind, habits of the heart, and habits of the hand”, which can be understood as apprenticeships for learning how to think, how to perform and how to act in specific disciplines or professions (Best et al., 2021). Signature pedagogies are not just educational practices but should also enable students to think and act like other scientists in their field (Crookes et al., 2020). In the context of this study, and coinciding with Boix Mansilla and Chua (2017, p.93), signature pedagogies are understood as practices that are performed towards gaining competency in a discipline or a profession. Even if they are thought to be stronger within professions, signature pedagogies also exist in disciplines (Poole, 2009, p.54). Originating in the Scholarship of Teaching and Learning (SoTL), especially at the undergraduate level, signature pedagogies have previously provided windows into the cultures of a field and its professional values (Golde, 2007). As instructional recommendations for education, signature pedagogies are richly discussed in the existing literature. For example, in educational research (Golde, 2007; Olson and Clark, 2009), chemistry (Gravelle and Fisher, 2012), food systems (Valley et al., 2018), medicine and law as initially discussed by Shulman (2005), and many others (for example, see Chick et al., 2012).

As discussed in chapter 2, CDT-OPTIMA students possess a disciplinary identity because they have been encultured in a discipline through specific
signature pedagogies. Therefore, students have already cultivated specific “habits of mind” (Gauld, 2005) that come to be confronted by different disciplinary pedagogies and habits during their doctoral programme.

Signature pedagogies and habits of mind are critical in interdisciplinary research and training, as evidence suggests each discipline possesses its own signature pedagogies (Abbas et al., 2016, p.9; English, 2016). As an example, Leven related the following thoughts about exchanges with a supervisor from a different discipline than their own:

There’s like a vague level of understanding but it’s a bit sometimes like we’re talking different languages. I find with [supervisor’s discipline], it’s a completely different approach to science to [Leven’s primary discipline]. It’s not just that they know things differently, it’s that they approach science in a different manner and our understanding of science is different. So that’s something that eventually I need to pick up (Leven).

Leven’s statement was often heard during this research project and perceived as the root of many difficulties in interdisciplinary research and training. Signature pedagogies have a substantial role in shaping students’ identities and become hidden from view once in place. Because this translates into students developing habits of mind, these practices become unconscious and result in what is often talked about as “disciplinary bias” (Trussel et al., 2017). On the other hand, these habits of mind are also the results of practices that allow students to enter the scientific research culture (Dewey et al., 2021).

This problem of culture between different disciplines often forms the basis for the advice offered to interdisciplinary students and novices through the
integration of disciplinary modes of thinking (e.g. Repko, 2008). For Repko (2008, p.19), modes of disciplinary thinking include “how each discipline thinks, approaches problem-solving, conducts research, and creates new knowledge” so that information from different disciplines can be identified and blended to address a specific question or problem. While knowing what to learn in a discipline is difficult, further learning is also necessary for working across disciplines. For example, students should be attuned to how learning occurs in different disciplines, the use of different languages and “have to learn how to operate in the ambiguous space between the disciplines” (Nash, 2008). While there have been attempts at formulating border-crossing and integrative frameworks for Science, Technology, Engineering and Mathematics (Leung, 2020), little is known about interdisciplinary habits of mind and the pedagogies used to encourage them, except for the recent work of Newell and Luckie (2019).

As CDT-OPTIMA students bring their own pedagogic identities to their doctoral programme, they are confronted with new habits of mind from different disciplines that they must attempt to master without supportive signature pedagogies in place to help them navigate the ambiguous space between the disciplines. Practising in such spaces is the focus of the analysis of the next section.

7.2.4 The space between the disciplines

While signature pedagogies are helpful, they pertain to the teaching function of universities and help nurture students into professional practices (Boix
Mansilla and Chua, 2017). Signature pedagogies and habits of mind are some of the central features of universities and are performed in laboratories, lecture theatres and seminars. To this extent, doctoral supervisors are engaged in helping students develop these habits through feedback, questions, discussions, and sharing methods and knowledge. This point will be further pursued in section 7.2.5, where I will discuss the notion of relationality in doctoral training.

Students encounter signature pedagogies during their whole educational journey but may not be fully aware of them, or they may only be implicit in the teachers’ practices. The practices and epistemic tools of particular academic disciplines, on the other hand, confront interdisciplinary students head-on, resulting in genuine discomfort, as epitomised by Tweed:

> There was a time when I put an equation on one of the slides, and I remember looking…there was a girl in the audience who was just like what on earth, and she just completely lost interest, so I’m never doing that again. I can still remember exactly how she looked like she, it was almost like she looked disgusted to see an equation. Honestly, it was so bad… (Tweed).

Tweed describes one of these moments when students can experience discomfort in the in-betweenness of academic disciplines during a talk to the research group. As discussed in section 1.3.2, CDT-OPTIMA is administratively located within the School of Chemistry at the University of Edinburgh, where a handful of students are also based. Other students are found at various locations and belong to other research groups, for example, the Centre for Inflammation Research (CIR) at the Queen’s Medical Research Institute (QMRI) based at Edinburgh’s Royal hospital. QMRI is an
interdisciplinary hub with an emphasis on bench-to-bedside science to address major disease challenges. Despite the interdisciplinary training of peers in Tweed's research group, introducing an equation in a presentation—a tool primarily associated with Physics—led to a challenging situation as the audience was mainly drawn from the biomedical sciences, so the speaker and the audience member and their disciplinary cultures clashed (Strober, 2011a). Scientific habits of mind are necessary for students' membership in a community of researchers that composes the university. But habits of mind also prohibit the notion of a research community as a homogenous group since they are specific to disciplines and sub-disciplines and render interdisciplinary conversations extremely difficult (Strober, 2011b).

In the later years of the doctoral programme, students discuss how they have become more skilled and confident, but the space in-between disciplines is not always more comfortable. Fyne revealed during an informal conversation that fitting in is the trickiest part of being an interdisciplinary doctoral student because of a lack of background in the disciplines involved in their project. Fyne concludes that because “I can’t argue my point, I have to rely on people who say they know what they are talking about.” Whereas Tweed chose the wrong tool to make a presentation (the equation), Fyne is struggling to claim expertise in the disciplines in which they were not trained and, therefore, feels like “I don’t fit anywhere and am the dumbest in all the groups” (Fyne).

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Working confidently with specific habits of mind confers on researchers a certain expertise status. Even as a doctoral student in an early career stage, disciplinary habits of mind indicate a level of expert knowledge – a level at which students start to gain credibility and legitimacy. As demonstrated by Fyne, a perceived lack of disciplinary habits of mind in some fields can be seen as lacking intellectual rigour. How the scientific community reacts depends on the make-up of this community. Some disciplinary scholars may agree with Fyne that interdisciplinary knowledge is broad but not specialised enough. Scholars trained in or practising interdisciplinary research may favour other skills that Fyne can contribute to team research. Interdisciplinary skills take time and practice to develop, but students eventually feel like they speak different languages (section 5.3), at which stage they are well placed to work collaboratively. These different views, and those in-between, will be the product of the other scholar’s system of habitus (Bourdieu, 1977) and how they perceive and value different types of capital (Brennan et al., 2017, p.240). Students will also evaluate the form of capital they think they possess; for example, Fyne notes: “I am the glue in groups, which makes it possible for everyone to come together”. Here, I interpret Fyne’s comment as bringing individual members together in a group through an ability to use languages and descriptions as translational devices (Pountney and McPhail, 2017) between disciplinary differences.

Fyne’s comment is a reminder that breadth versus depth of knowledge are issues often encountered in interdisciplinary research. However, this particular position is not shared by all the students equally. For example,
Ettrick admits that “I like to learn a lot of things in less depth rather than one thing in a lot of depth.” However, there is still a recognition in this statement that depth is an important consideration in scientific practices.

Working in the space between the disciplines can also be confusing regarding expectations about the science project, as noted by Coe:

…my first supervisor is a [disciplinary identity] so this must be the main part of my project, and [other disciplines] will be something nice to learn next to it but not the main thing. The problem was both my supervisors and I had completely different expectations of my PhD (Coe).

Coe was referring to their first supervisor’s discipline and had anticipated this discipline would drive the project. In such cases, individual students reported being allowed to steer the project toward their own interests but highlighted the problem of students’ expectations of their doctoral programmes.

Students’ expectations have been shown to vary across individuals depending on their circumstances and the level of support from supervisors and contact with their peers (Candy et al., 2019). Nevertheless, this study has identified difficulties when working across disciplines and labs that traditional PhD students hardly encounter. For instance, during the group interview, Doon explained how it is difficult to work for two lab groups and the fact that no-one necessarily takes responsibility for the student, meaning it is “easy to fall in gaps” (Doon). The problem Doon discussed was knowing who to turn to when support is needed, for example, knowing how to go about purchasing laboratory equipment for their experiments. During the business and entrepreneurship taught modules, CDT-OPTIMA students are given projects to work on so they can apply what they are learning through
scenarios on how they would pitch their innovation, making sure it is economically viable, estimating project costs, and so on. According to a discussion with CDT-OPTIMA management, the earlier cohorts of students on CDT-OPTIMA were given made-up projects that did not meet their expectations as these did not feel real enough. The next cohort of students was given past projects, which were found inadequate by the students as they had already been done. Finally, in 2019, the participants in this study were introduced to the University of Edinburgh Healthcare Technology Accelerator Facility (HTAF)\textsuperscript{61} to work with their innovation and technology team on live projects. CDT-OPTIMA management pointed out on several occasions during this study that finding appropriate projects for students for the business modules was the biggest challenge they encountered. Coe noted the business modules were repetitive and did not understand why so many credits were needed since students are not awarded a master’s in business. Instead, Coe remarked the CDT-OPTIMA programme was not “that interdisciplinary, and it would be nice if you could choose some credits for yourself” (Coe). Almond noted that they had not been made aware of opportunities for postdoctoral positions after graduation.

These were among the many comments made during informal and interview conversations with the participants in this study and serve to exemplify how students’ expectations are not always met and can make their everyday experiences of their PhD training difficult. As well as the major structural

\begin{footnote}
\textsuperscript{61} HTAF website, online at https://www.healthcare-technology-accelerator.ed.ac.uk/about-us [Last accessed 20/10/2022].
\end{footnote}
barriers to interdisciplinarity in universities, attention should be paid to the smaller structures (Townsend et al., 2015). This study confirms previous findings that students’ expectations should be managed on a regular basis (Friedrich-Nel and Mackinnon, 2013), which is especially important for interdisciplinary students (Lyall and Meagher, 2012).

7.2.5 Relationships and interactions

Learning and training occur through social interactions and participation in practices (Lattuca, 2002) among embodied socialised agents (Collins, 2016). Practices of scientific training are the equivalent of learning the often tacit “rules of the game” (Mueller et al., 2016, p.53), implying the need for shared meanings and understandings (Schatzki et al., 2001, p.18) between members of the same community. Doctoral training is composed of multiple activities such as reading, writing, presenting, experimenting and analysing, where students learn by doing, through physical contiguity and immersion (section 2.3.5). While such actions will be familiar to most doctoral students and more mature scholars, it is essential to reiterate that practices are highly contextualised and dependent on new and existing practitioners, materials, competence, and meanings (see section 2.3.4). Therefore, practising may take different forms in different fields of research, departments, and universities. The participants in this study rely on learning with experts and peers and have to learn to navigate the different practices of the disciplines they work with, the labs they are assigned to, and they also need to learn how to fit in the research cultures of two universities (University of Edinburgh and the University of Strathclyde).
As mentioned earlier, practices that are highly recognisable in doctoral training (doing a literature search, writing a thesis, defending a viva voce examination) are activities that reproduce and re-enact PhD training. However, there are significant variations in practices, such as whether to publish research during the PhD, the amount of time spent in a lab/fieldwork, building networks, and the meanings behind the doctorate and how it is viewed. As discussed with a few participants in this study, meanings can also change quickly or co-exist at any time, even if they sometimes seem contradictory. For example, some participants mentioned that a period of doctoral training is a way of putting off working in the real world, but at the same time, it is part of preparing for a future job.

Learning and training practices are always embodied and are, hence, performed by people (Schatzki, 2001b, p.11) or students in the case of this research. Based on this principle, knowledge is conceptualised as a shared process sustained through social interactions rather than an object people possess (Mueller et al., 2016, p.53; Tooman et al., 2016, p.25).

Whereas traditional doctoral training is predicated on the master-apprentice model of the early universities (Lindvig, 2018; QAA, 2020, p.3) and the dyadic student-supervisor relationship (Bastalich, 2017; González-Ocampo and Castelló, 2019; Lee, 2008), interdisciplinary doctoral training necessitates multiple relationships and interactions including supervisors from different fields, student cohorts, experienced researchers, research networks and epistemic communities (Boud and Lee, 2005). CDT-OPTIMA
participants also face multiple relationships and interactions in two different universities, adding to the complexity of their practices. Eyler (2018) used the concept of “social pedagogy”, which fits with the practice lens of doctoral education, to argue for the need to consider relationships, role models and the larger community as key factors in student motivation, performance, and retention. Similarly, Baker and Lattuca (2010) invoke the concept of “developmental networks” in their study of learning and socialisation.

Relationships and interactions are important for any kind of learning but especially so for interdisciplinary training and were observed to be one of the most important aspects of the doctorate in CDT-OPTIMA. Leven, who had experienced feelings of isolation in labs, explained there were not many people to talk to as nobody else was doing the same kind of research and described how they welcomed the arrival of a new postdoc in the lab.

She’s a [disciplinary identity], so it’s been really helpful, so there’s someone I can talk to literally about the stuff I work with […]. It’s amazing when there is just one person who’s kind of doing what you’re doing. It helps a lot (Leven).

In Leven’s and many other CDT-OPTIMA students’ cases, supervisors do not tend to figure prominently in the labs, pointing to the importance of learning through proximity to experts and the concept of contiguity discussed in section 2.3.5. In contrast, when supervisors are present in labs or have experienced interdisciplinary work, students feel much more supported, as was reported by Spey. The presence of peers and experts is crucial to the development of new researchers because the opportunity to observe the
practices of more experienced researchers and to question them allows students to develop their skills and progress towards hands-on practice (Ribeiro, 2013). Experienced researchers do more than model how to perform their disciplines, but also model preferred ways of interacting, making decisions, and responding to challenges (Kuh et al., 2010, p.157) and the variety of other tacit knowledge needed to develop expertise (section 2.3.5). During a doctoral programme, students must immerse themselves in the culture of scientific research (Dewey et al., 2021) and the cultures of different disciplines for interdisciplinary programmes (section 2.1.4). These processes facilitate the students’ socialisation in different communities and the development of their professional and academic identities (discussed in section 7.2.1). In turn, the mobilisation of a professional identity helps students develop their collaborative skills and improve the way they can think like a member of the team (Best et al., 2021).

The evidence from this study points to the concept of relationality for understanding how CDT-OPTIMA students navigate the complex learning environment in which they practise and to the crucial role played by social interactions in doctoral training. The study also highlights the importance of the level of immersion needed for students to acquire all the skills to work in different disciplines. My interpretation of how to develop expertise in a given field and at the doctoral level, thus, depends on gaining experience with experts, which involves a mixture of doings and sayings that are found in the semantic and resources worlds, and the relational space discussed earlier. The concept of immersion advanced by Ribeiro (2013) provides a theoretical
framework (discussed in section 2.3.3) to help explain the difficulties CDT-OPTIMA students experienced in the absence of experts and provides a nuanced understanding of learning as participation in the practices of a specific community as discussed by Lattuca (2002). This latter point is corroborated by Collins and Evans (2018) when they affirm that “the expert is, then, an individual who has gradually acquired skills through sustained practice”. Thus, expertise is an outcome of socialisation, which stands in contrast to CDT-OPTIMA students’ feelings of isolation, as discussed earlier.

The “self-study” level of immersion is easily recognised in all doctoral training and can be associated with the literature review stage of the PhD. Students gather information about their topic of research by themselves, through extensive reading of the existing literature. “Linguistic socialisation” helps acquire fluency in the disciplines or what Collins (2011) argued was the basis for interactional expertise. However, this fluency comes only from a long and deep immersion in the linguistic discourse (of the disciplines) in order to obtain tacit knowledge (Collins and Evans, 2018). This point is where socialisation with experts starts, according to the levels of immersion from Ribeiro (2013) and the recognition that expertise is obtained through socialisation into bodies of tacit knowledge (Reyes-Galindo and Duarte, 2015). In interdisciplinary doctoral training, it should be recognised that being able to communicate across the disciplines is a crucial element and refers to students’ comments in my sample on their abilities to speak different languages. Linguistic socialisation, as observed in this study, is the outcome of interactions between students and experts in a range of contexts, such as
lectures, seminars, and supervisory meetings. “Physical contiguity” refers to the ability to observe practices without involvement and where students have the opportunity to question experts (see Ribeiro and Lima, 2015). This process is akin to asking knowledgeable peers about how something is performed and being present to observe the practices as they happen. The ability to practice, then, allows individuals to develop their own skills and understandings and to apply them in different situations. It is through this involvement and immersion in practices that students develop lived experiences of what it is to be practitioners.

Finally, the concept of immersion, as used in this study, has generated an important insight into the development of new interdisciplinary researchers. Just as CDT-OPTIMA students need to be in close proximity to disciplinary experts to acquire skills across different disciplines, so should new interdisciplinary researchers learn from the practices of interdisciplinary experts. As discussed in section 2.2, interdisciplinarity is often examined through the level of integration of disciplinary insights, which contrasts with the following participant’s understanding of interdisciplinarity:

In my thesis, I will have a chapter on [discipline A], one on [discipline B] and one on [discipline C], so I feel truly interdisciplinary (Thurso).

Therefore, when the integration of insights from different disciplines is truly the expected outcome of interdisciplinarity, then it should be formally recognised as a skill and needs to be taught by developing the experiences of doctoral students with interdisciplinary experts.
7.2.6 Work placements

CDT-OPTIMA students must undertake a mandatory three-month work placement in the third year of their doctoral programme in a commercial setting of their choice (worth 60 credits). The degree regulations for this module\textsuperscript{62} state that “students can expect to gain a first-hand experience of a range of perspectives on industrial practices, policy, innovation and entrepreneurship” and list the following learning outcomes:

- Experience of the challenges of working in a commercial environment.
- Experience of the differences in working practice between academic and commercial environments.
- An appreciation of the criteria that must be met for a scientific idea to have commercial potential.
- Experience of report writing to commercial and professional standards.

These outcomes stress the role of the work placement as an activity for students to consolidate their learning in the business and entrepreneurship taught modules of the PhD programme. The placement assessment section of the regulations states the students will provide a project report, including a literature review, will present this report orally to peers and management of CDT-OPTIMA, and the placement supervisor will return a performance report. The difficulty for assessors was trying to identify the outcomes of the work placement in a quantifiable manner, for which I suggested the use of

\textsuperscript{62} Degree Regulations and Programmes of Study (2018/19) for module CHEM11051 is no longer available online. Information drawn from a personal copy.
the Researcher Development Framework (RDF) provided by Vitae°.

Students were given the RDF in a Microsoft Excel format and provided with a link to the Vitae website for instructions, then asked to plot their personal qualities, knowledge and skills before and after the work placement. The use of this framework is limited in that it is a self-assessment, but CDT-OPTIMA students reported during informal conversations during this study that it forced them to reflect on their experiences, which was viewed as a positive outcome. Figure 13 details the four main domains and twelve sub-domains of the RDF:

<table>
<thead>
<tr>
<th>Domain</th>
<th>Sub-domain</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Knowledge and Intellectual Abilities</td>
<td>(A1) Knowledge base</td>
</tr>
<tr>
<td></td>
<td>(A2) Cognitive abilities</td>
</tr>
<tr>
<td></td>
<td>(A3) Creativity</td>
</tr>
<tr>
<td>B - Personal Effectiveness</td>
<td>(B1) Personal qualities</td>
</tr>
<tr>
<td></td>
<td>(B2) Self-management</td>
</tr>
<tr>
<td></td>
<td>(B3) Professional and Career Development</td>
</tr>
<tr>
<td>C - Research Governance and Organisation</td>
<td>(C1) Professional conduct</td>
</tr>
<tr>
<td></td>
<td>(C2) Research management</td>
</tr>
<tr>
<td></td>
<td>(C3) Finance, funding and resources</td>
</tr>
<tr>
<td>D - Engagement, Influence and Impact</td>
<td>(D1) Working with others</td>
</tr>
<tr>
<td></td>
<td>(D2) Communication and dissemination</td>
</tr>
<tr>
<td></td>
<td>(D3) Engagement and impact</td>
</tr>
</tbody>
</table>

*Figure 13: Domains and sub-domains of the RDF*

A large part of the students’ written reports was to identify the sub-domains in which they perceived a change after the work placement and to provide evidence for that change. The most changed elements of the RDF postplacements were found in the domain of personal effectiveness and sub-

° Vitae, online at [https://www.vitae.ac.uk/researchers-professional-development/about-the-vitae-researcher-development-framework/developing-the-vitae-researcher-development-framework](https://www.vitae.ac.uk/researchers-professional-development/about-the-vitae-researcher-development-framework/developing-the-vitae-researcher-development-framework) [Last accessed 12/12/2022].
domain B3 professional and career development within descriptors of self-confidence, networking, time management, career management and responsiveness to opportunities. Sub-domain A3 (knowledge and intellectual abilities – creativity) and sub-domain D2 (engagement, influence and impact – communication and dissemination) were also identified as most changed relating to inquiring mind and communication methods, respectively. These findings highlight that work placements during CDT-OPTIMA doctoral programme were important to students individually, with an emphasis on self-confidence and creativity as the two skills that increased the most.

Self-confidence was noted by students as the confirmation of the value of their skills outside academia. As early career researchers, PhD students are often confronted with more experienced researchers and may not be as confident about their level of knowledge. In contrast, the workplace provides a space where their knowledge is highly valued and where the students’ opinions are sought and listened to. The quote below supports this insight:

> My boss, she was super intelligent, she was like at the top of the field, but yeah, some of the science stuff, if she read it off a paper, she wouldn’t get it, but you need to explain in a way that makes sense to the people that haven’t done the science (Spey).

In this quote, Spey identified the level of expertise of their boss as extremely high, but it was Spey who could explain a research paper in simple enough terms for non-scientists to understand.

Students talked about developing their inquiring minds while on the work placement, which seems to be connected to the fact that they were also
developing their self-confidence. Students reported being able to solve problems, express opinions, ask questions in order to develop their knowledge and also noted the importance of developing strong professional relationships. Most students recognised that a strongly supportive and stimulating environment was a crucial factor in making their experiences enjoyable and for promoting learning. Forth noted how the experience felt empowering and:

People come back and tell you you’re doing great, that’s a fantastic piece of work, and you’re like, wow, I did that of my own volition, like my supervisor didn’t tell me to do that (Forth).

Overall, the inclusion of a work placement during doctoral training was felt very positively by CDT-OPTIMA students who were able to take a break from their PhD, work in teams as opposed to being isolated in labs, strengthen their skills and confidence and try out a possible career.

The work placement part of CDT-OPTIMA is highly biased towards experiencing the workplace in industry and, as such, lacks a balance towards improving students’ research skills (C - Research Governance and Organisation) or reinforcing a professional identity, although the placements result in a heightened sense of expertise. This study found that through the students’ constant comparisons between academia and the real world, work placements reinforce the idea of separation of the two sectors and show little evidence of strengthening movement and collaboration between academia and industry as claimed in political strategy documents in the UK (BEIS, 2021, p.6). Specifically:
• Work placements can be said to raise “awareness in businesses of the expertise that exists in the UK’s universities” (Lambert, 2003, p.33). However, these placements are at no cost to businesses since students are paid a stipend and full expenses from CDT-OPTIMA’s grant. It is not certain that businesses that do not normally recruit doctoral graduates will change their practices.

• A small but significant number of students are offered employment in the organisation in which they carry out their work placement. These offers imply that either students have to leave their PhD programme before they can be completed or reject offers. This point further highlights that while businesses value students’ skills, they do not value the PhD (as a qualification) per se.

• While students are free to choose the organisation in which to undertake the work placement, CDT-OPTIMA management appraises students’ proposals. However, a difficulty lies in identifying how a placement supervisor is adequately qualified to train students or to specify the type of training that is expected.

• Three months is a relatively short time in which to build lasting relationships with the host organisation. Other types of PhD exist, which stress the intensity and continuity of collaborations (e.g. Kitagawa, 2014; Kitagawa, 2016).

Overall, the mandatory work placement is a useful tool for future careers, giving students the opportunity to experience a different work environment and responsibilities that can then be highlighted on a resume for future job
opportunities. Academically, the work placements can be seen as valuable when taking into consideration that students feel more self-confident. However, a major challenge remained for CDT-OPTIMA students in the timing of the placement and was discussed by a majority of students in the field. The end of the third year is a delicate stage when students hope to finish their lab experiments, so they have gathered all their data for the thesis. Students working on live cells found it difficult to drop their experiments and were worried about having to start again after the placement. Generally, the positive experience of working was felt by students as motivational for finishing the PhD as they felt refreshed after having taken a break from their studies. As far as sustaining relationships between academia and industry or translating science into innovation, I was not able to establish any links. One of the reasons for this is that such relationships cannot be identified in the short term and would merit further empirical and longitudinal research to investigate students’ careers in the longer term.

Debates around the purposes and practices of doctoral training are aspects of the curriculum – what students learn during their degree rather than how (Gilbert 2009). From this perspective, it is difficult to see how the CDT-OPTIMA work placement figures in a structure that promotes research training. The idea of a curriculum in doctoral studies is often described as a “missing term” because it is little referenced and inadequately theorised (Green, 2012) and has been shown to be even more challenging to develop for interdisciplinary doctoral programmes (Holley, 2009a). The findings of this study emphasise that the establishment of a thoughtfully planned curriculum
could help students develop their competencies based on clear learning objectives. In the case of interdisciplinary doctoral programmes, a curriculum should develop students' understanding of integration of knowledge across disciplines (section 2.2) or a deeper understanding of the different modes of knowledge production (sections 2.2.2 and 2.2.3) so students have a better sense of their developing ways of practising in academia. In the case of translational science and entrepreneurship, as in the case of CDT-OPTIMA, the curriculum should not emphasise the differences between working practices in academia and industry but should highlight the role expected of students in bridging these two sectors. As it stands, the work placement signals to policymakers that students may be ready for work in industry but offers little in the way of a learning strategy, and its effectiveness for securing employment after graduation may be limited.
This thesis investigated interdisciplinary doctoral training in the context of UK research and education policies that seek to boost the country’s economic productivity through the translation of scientific research into innovations. The link between interdisciplinarity and innovation is often taken for granted, at least in the political rhetoric that demands universities play a crucial role in boosting the nation’s performance. The government’s vision for the role of universities in society deviates from the traditional goals of these long-standing institutions, whose concerns have always been the production of knowledge and the training of experts. Thus, the situation raises important questions regarding the rationale behind the perceived value of interdisciplinary research training in policy and how these policies are enacted and affect students’ training and understandings of the doctorate and universities. This thesis aims to answer the main research question: how are UK interdisciplinary policy intentions enacted in doctoral training?

The scholarship on interdisciplinarity depicts messy understandings of this concept with ongoing debates surrounding definitions, methodologies and controversial perspectives on the role of academic disciplines (Vieini-Baptista et al., 2022). The present study provides empirical evidence on the type of interdisciplinarity performed in CDT-OPTIMA, thus adding to efforts to offer some clarity on how the term interdisciplinary is used in this particular
context and in response to the research question that asked: what are the features of interdisciplinary research training offered by CDT-OPTIMA?

A second sub-question was devised to interrogate how interdisciplinarity is performed in CDT-OPTIMA. This question is directly concerned with the participants’ experiences and everyday practices, following concerns in the existing literature regarding issues of supervision (Taylor, 2018), becoming competent in a field (Fam et al., 2017) and students’ expectations from their training programme (Candy et al., 2019). Furthermore, research has shown risks (Rhoten and Parker, 2004) associated with pursuing interdisciplinary research and progressing in academia and the structural constraints presented by the disciplinary organisation of universities (Lindvig et al., 2017). Little is currently known about how these concerns affect interdisciplinary doctoral students in the UK, although the doctorate is under constant review from the research councils in a bid to align the qualification with the government’s aims to train students as the future agents for technological progress.

Finally, the main research question required the analysis of a sub-question on how interdisciplinarity is formulated in UK policy strategies for the training of new researchers in order to understand the policies and politics behind knowledge production in universities. This final sub-question addresses the policy turn to interdisciplinary research as the context in which students develop their intellectual abilities for a future profession. While I argued that universities have always been responsive to society’s needs, the push to
innovate and produce scientist-entrepreneurs is at risk, according to some scholars, of rendering universities subservient to an economic imperative to the detriment of their intellectual mission.

In other words, this thesis examined the university and the doctorate as sites of politics (see section 3.6), where differing constructions of interdisciplinarity and multiple research practices co-exist, sometimes coming into tension. From a doctoral training point of view, I suggest the politics of interdisciplinarity are akin to a “regime of collective experimentation” (Felt and Wynne, 2007, pp.26-27), where new approaches to the PhD are to be found and experimented with to train a specific type of scientist to boost the progress of the country. Academia is under pressure to perform for the best interests of its many stakeholders and to move away from the traditional norms, values and organisational models that have underpinned academic life for the last two centuries.

8.1 Interdisciplinary PhD as an innovative practice

Governments worldwide continue to promote interdisciplinarity for the production of innovation and for accountability purposes (Barry et al., 2008). This section describes the interdisciplinary doctorate as a social practice of academia to examine whether it counts as an “innovative PhD”, taking into account what has been learned during the present study.

Earlier (section 2.2), I observed that interdisciplinarity was not something new in academia and nor was a relationship between science and society. In the UK, this has led to numerous reviews of the doctorate and the investments in
“new variants” of the PhD (section 2.1.2), such as the interdisciplinary PhD in a CDT model under investigation in this study. In what follows, I apply the lens of practice theory (section 2.3.5) to discuss whether the interdisciplinary PhD is actually a new form of education by examining the idea of the PhD through the practice architectures discussed in Kemmis and Mahon (2017, p.111).

**The semantic world**

The semantic world refers to language and discourse. Ideas about what the PhD is in society is a useful lens that provides collective, broadly and deeply held imaginaries about the qualification (Kelly, 2017, p.5).

The doctorate is the highest qualification obtainable in education, pointing to an “elite” position and is obtained after a period of original research, the writing of a thesis and an oral examination. The aim of the research is to produce original knowledge in one’s discipline, and the training is designed to increase the intellectual capabilities of students. The PhD candidate will possess certain skills and attributes upon graduation: specialist knowledge, effective communication and general intellectual capacities (Kelly, 2017, p.45). Upon graduation, graduates can expect to obtain highly-skilled work, either in academia or non-academic sectors and be active in work for the prosperity of the nation (BEIS, 2021).

The “sayings” involved in the semantic world involve cognitive aspects, competences and know-how. This can be thought of in terms of disciplinary
repertoires (methods, concepts and theories), computing skills, how to read an article, and previous educational experiences.

**The world of resources**

Resources are the medium for activity and include all sorts of objects and spaces: universities, regulations, lecture theatres, books, articles, libraries, laboratories and equipment, as well as time resources: timetables, deadlines, programme length (to be balanced against home/family/leisure time). Under this heading, I would also include the larger environmental conditions: availability of funding, increased competition in the job market, academic hierarchies, access to fieldwork, university management and support services, and material resources.

**The relational space**

This space relates to roles and relationships with peers, lecturers, supervisors, and interactions with individuals in meetings, seminars, guest talks, summer school, support staff, technicians, participants in research, ethics boards, examiners, and graduate office. It includes knowing when to perform certain activities in ways that are appropriate and related to available resources and competences. For example, this study has shown there is a relational aspect between knowing what to say, to whom and in which setting, and the need to pay attention to shared meanings in interaction (discussed in section 7.2.5).

Interdisciplinary doctoral training, in this perspective, already looks very familiar, except for the competency aspects that are needed in two or more
disciplines instead of just one. I contend, thus, that interdisciplinary doctoral training does not constitute a different type of practice from disciplinary training but that it amounts to a re-invention of the PhD: a degree that is very similar to what are already well-established practices but with the addition of one or more disciplines.

So far, the discussion has depicted a straight-forward model of doctoral training, as if from a policy perspective. Put in a different way, it seems policies argue for novel doctoral training by pushing for knowledge in more than one discipline in relation with industry and for solutions to societal problems. However, adding up disciplinary knowledges does not necessarily imply integration nor interdisciplinarity (Silvast and Foulds, 2022b, p.9), and nor does it qualify interdisciplinary knowledge as “superior” to disciplinary findings (Jacobs and Frickel, 2009). This view is problematic for the training of students and ignores social relationships in research as a crucial element in the way students learn in practice. The problem is virtually absent when considering the classical disciplinary doctorate as the structures of traditional universities provide “ready-made” disciplinary communities of peers already but leads to difficulties and tensions for interdisciplinary students, who lack role-models (section 7.2.5).

Also in section 7.2.5, I argued that learning occurs through social interactions and participation in practices (Lattuca, 2002) to allow students to enact the “rules of the game” of academic research and that interdisciplinary research training necessitates multiple relationships beyond the dyadic student-
supervisor interactions. The fact that CDT-OPTIMA students reported working in labs where there are limited or no opportunities to discuss and share their research with peers is arguably the most detrimental issue to their development. I maintain that the lack of role models for my participants adds to the difficulties in navigating their doctoral training and overlooks the crucial issue of participation in practices in favour of the traditional conceptualisation of learning as “acquiring knowledge” (Schatzki, 2017). Thus, the concept of “socialisation” of students (section 2.1.4) becomes problematic in interdisciplinary doctoral training when expertise is taken to be a property of individuals rather than a “performance” (Collins and Evans, 2018).

8.2 Performing interdisciplinarity

Developing abilities in different disciplinary practices requires immersion with experts as mastery “must involve social interaction with the relevant community as, without this, the tacit knowledge of the domain can never be attained” (Collins and Evans, 2018). Here, the concept of immersion, as proposed by Ribeiro (2007; 2013) and Ribeiro and Lima (2015), as discussed in section 2.3.5, is significant for the present study. By linking the concepts of practice and expertise, Ribeiro and colleagues extended the work of Collins (2004) and Collins and Sanders (2007) in their Studies of Expertise and Experience by identifying that between linguistic socialisation and physical immersion lies the need for physical contiguity or “the proximity to the practices of a domain that falls short of active involvement” (Ribeiro, 2007, p.713). That is, in order to learn, students require to grasp some of the tacit knowledge employed by experts in their practices through observation, and
expertise grows over time (Ribeiro, 2013). Not only, then, is physical contiguity necessary for learning, but it needs to be sustained over time. From this perspective, students who are supervised by interdisciplinary scientists and who are present in the labs, so students can observe how they go about running experiments (“doing science”) for example, are much more advantaged than students who are working on their own, without close proximity to peers or experts.

One of the difficulties experienced by many CDT-OPTIMA students, as identified in the present study, lies in the isolation of students from each other, from peers who can talk about and show how practices are carried out and, more generally, from interdisciplinary role models. This issue points to a lack of physical contiguity in interdisciplinary training that makes it particularly harder for students to check their understandings of science and leaves them to deal with situations that were unforeseen and remain hidden in interdisciplinary practices. Thus, the lack of access to experts is considered in this study to be an intensifier (Winchester-Seeto et al., 2014) that makes the PhD programme more complex, difficult and stressful and also impedes the socialisation of students. Interdisciplinary students experience the additional burden of having to develop scientific networks to strengthen their abilities and competencies. Moreover, these abilities are a crucial part of the PhD training but remain undervalued because they are not part of the traditional assessment criteria of the doctorate.
In terms of interdisciplinarity, the above discussion points to the students’ difficulties in defining their expertise when they talk about being a “jack of all trades”, for example. Disciplinary specialisation is associated with particular kinds of professional expertise that provide legitimacy and status (Moran, 2010), while interdisciplinarity is often understood as being underpinned by expertise in research integration (Bammer et al., 2020). Thus, it proves difficult for CDT-OPTIMA students to articulate their area of expertise using the concept of interdisciplinarity. A more useful conception of CDT-OPTIMA’s field of research as an interdiscipline (discussed in section 8.3.1) in which students are socialised would point to a specific professional expertise that involves strong contributory expertise in one field and extensive interactional expertise in other disciplines, underpinned by excellent tacit knowledge. The problem of socialisation of students in interdisciplinary programmes has significant consequences for students’ sense of identity (chapter 2), which is addressed in the next section.

8.3 The interdisciplinary chimera

There is great disparity around the concept of “interdisciplinarity” in the existing academic literature, policy documents, and in the multiple practices of researchers, leading to multiple understandings and definitions (Vienni-Baptista et al., 2022). My findings confirm that interdisciplinarity is thus a fluid concept that is attached to research as a label without necessarily reflecting the degree of integration of different disciplines (see section 2.2). The perceived need for interdisciplinary research and the will to engage with such research is not without difficulties and risks for PhD students who find
themselves working at the intersection between different institutions: academia, government, and industry. These “triple helix workers” (Thune, 2010) need to adapt to a host of new practices that were not part of postgraduate education in a distant era when scholarship was the close supervision of students to develop their intellectual capabilities with the view to teach in universities. Yet, there seems to be a consensus in the research and the policy communities that interdisciplinary practices are needed in order to integrate what is viewed as the fragmented knowledge of the existing research landscape.

The situation has led me to think of interdisciplinarity as a “chimera”: a mythical creature composed of different body parts, as described by Pooley et al. (2014): a lion’s head, a goat’s body, and a serpent’s tail, as per figure 14.

Figure 14: The chimera (graphic retrieved from the Florida Center for Instructional Technology, online at https://etc.usf.edu/clipart/17900/17930/chimera_17930.htm, last accessed 27/11/2022).
As depicted in the graphic above, the creature has three heads: each would represent a different discipline. The body would be a representation of the functions of scholarship: discovery, integration, application and engagement, and teaching (Boyer et al., 2016) and the tail would point to possible futures. This creature’s legs may represent knowledge, skills, expertise and employability and, thus, grow with time. The metaphor implied here is not meant to be an exhaustive description of “interdisciplinarity” as an entity, nor does it encompass the plurality of understandings of the concept. Instead, it is a figure of speech that draws attention to important issues (Maasen and Weingart, 2000, p.2). Namely, interdisciplinary practices are not like the disciplinary norms of universities, and despite the growth of interdisciplinarity, may still be seen with suspicion in academia (Graff, 2016).

The numerous metaphors employed to describe interdisciplinarity also point to another issue: the concept is so difficult to explain that metaphors seem to be an inextricable part of making sense of interdisciplinarity. None of the existing metaphors in use is without problems, but they remain pervasive: participants in this study talked of “speaking different languages”, Repko (2008, pp.22-24) discusses “boundary crossing”, “bridge building”, “mapping” and “bilingualism”, Rosso (2019b, pp.92-93) talks of “wedding banquet” and a “band of musicians”, Castree and Waitt (2017) use “completing a jigsaw”. Klein (1990, pp.80-81) introduces more metaphors and discusses, in

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particular, the organic metaphor noting it asserts interdisciplinarity’s “natural” place.

The metaphor of the chimera suggests at least three main issues reflective of the challenges of interdisciplinarity:

- It is difficult to identify the parts that make the whole.
- It is not entirely clear how the parts are put together.
- There is no consensus regarding what the components are or should be.

This perspective is a return to the challenges discussed previously: what constitutes interdisciplinarity if disciplines are already highly connected, and how is knowledge integrated (section 2.2), thus, what exactly is interdisciplinarity? In the next section, I describe how I interpreted the evidence from CDT-OPTIMA and make the case that medical optical imaging is actually an *interdiscipline* in the broad field of biomedical sciences rather than the type of interdisciplinarity that requires integration. From this perspective, the CDT-OPTIMA doctorate was not found to be truly different from a traditional PhD in other “portmanteau” fields such as STS, geopolitics, or economics. However, a praxeological examination of CDT-OPTIMA students’ experiences reveals key underlying issues with this specific type of doctoral training, not because of the interdisciplinary nature of the field but because individuals and institutions engage in practices that reinforce the view that interdisciplinarity is not the norm in academia and thus, (re)produce a sense of marginality (section 6.3).
When a doctoral degree is considered a process of disciplinary identity development, interdisciplinarity poses challenges to the training of scholars (Holley, 2015). The participants in this study articulated how they feel different from other students, and I consequently argued (chapter 5) that the lack of role models in academia affects students’ learning. I argue that because interdisciplinarity and its students are “othered” (Lindvig, 2018; Lindvig and Ulriksen, 2019), they are seen to occupy a space of marginality. The concept of marginality has different meanings in the sociological literature, and following Billson (1988), I used the definition of “social role marginality”, or not belonging fully to a positive reference group (here, the traditional disciplinary PhD). Occupying a space of marginality can be understood both as a negative and positive position. Firstly, though, a distinction should be made between types of marginality, as described by the feminist theorist Hooks (1990, p.153):

I make a definite distinction between that marginality which is imposed by oppressive structures and that marginality one chooses as site of resistance—as location of radical openness and possibility.

The space of marginality I describe here is a space interdisciplinary students choose (wittingly or unwittingly) rather than something imposed on them based on race, ethnicity or gender characteristics, but influences how and why interdisciplinarity and interdisciplinarians are viewed negatively by some in academia. The fact my participants described themselves as “different”, not wanting to do “just lab work”, and clearly articulating how their PhD programme was not the same as other PhDs also points to the positive
aspects of marginality, as hinted by Hooks in the quote above. By positioning themselves as different, students also contributed to how they are viewed by those outside of CDT-OPTIMA and emphasised that they are special and innovative compared to the rest of the students, similar to experiences reported by Newell (2009). Thus, the space of marginality is also a space of resistance against the disciplinary organisation and teaching of universities, a space where students can follow their own interests, and a way to differentiate oneself through boundary work. Declaring oneself as different (from others) is a practice of classification that ties people to a set of work practices, beliefs, narratives, and organizational routines that constitute a kind of interdisciplinary entity (Bowker and Star, 2000, p.319). Classifications are powerful technologies and Bowker and Star (2000) discussed how categories become taken for granted and underpin common sense assumptions about individuals. In the case of interdisciplinarity, interdisciplinary doctoral students are thought of as breakings down barriers between disciplines, locations and sectors. Moreover, categories are judged against standards that valorise some points of view and silence others (Bowker and Star, 2000, p.5). Thus, if disciplinary doctorates are the standard in academia, interdisciplinary training is imagined as different, as belonging to a different group with different practices. Thus, interdisciplinarity is often (re)produced in practice as a specific type of research work where individuals are classed as being interdisciplinary. This position stands in place of an explanation of what interdisciplinarians actually do and points to
common sense assumptions about what interdisciplinarity is, despite the multiple understandings and definitions of the term (section 2.2).

The issue of practising in the space of marginality I wish to focus on in this discussion is a concern with legitimacy and its role in how knowledge and expertise are valued alongside criteria of relevance and credibility (Hansson and Polk, 2018). Firstly, though, I will discuss the implications of thinking with an interdiscipline.

### 8.3.1 Medical optical imaging as an interdiscipline

An interdiscipline is a mix of existing disciplines such as biochemistry, neuroscience (Repko, 2008, p.52), political psychology or psychohistory (Fuchsman, 2012). Interdisciplines can be considered as “hybrid” disciplines that retain part of the ideas, methods, or concepts from the parent disciplines (*ibid.*) or entirely new disciplines when they have developed their own perspectives, journals and professional associations (Repko, 2008, p.52). My contention is that optical medical imaging research, as practised by CDT-OPTIMA students, is an interdiscipline – as opposed to *interdisciplinary* - across the biomedical sciences that are defined by the Quality Assurance Agency for Higher Education (QAA)⁶⁵ as:

> The biomedical sciences are underpinned by a number of related sciences, including biology, chemistry, mathematics, information technology and, to a lesser extent, physics. Core biomedical sciences subjects include: human anatomy, physiology, biochemistry,

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genetics, immunology, microbiology, pharmacology, cell and molecular biology and Bioinformatics (QAA, p.4).

The level of maturity of the interdiscipline may be a matter of contention, but the evidence of its evolution is visible through its organisation as a subfield in healthcare, medical imaging and diagnostics. In Scotland, this organisation manifests itself through the Scottish Imaging Network: A Platform for Scientific Excellence (SINAPSE)\textsuperscript{66}. Due to the number of disciplines involved in the biomedical sciences, there are many journals in which manuscripts can be published, but medical optical imaging is a sub-topic in MDPI, a publishing company based in Switzerland\textsuperscript{67}. SINAPSE is a consortium of seven Scottish universities and therefore provides a growing platform for networking across the institutions. The difficulty in defining the word \textit{interdisciplinary} (section 2.2) is compounded when it is used for multiple-disciplinary fields – these fields are multidisciplinary at best and require little integration of the disciplines.

The medical optical imaging field of research can be understood as interdisciplinary because it is a field that is underpinned by various disciplines. However, if interdisciplinarity requires that disciplinary insights be evaluated and integrated, as per the most common understanding of the concept (see section 2.2), medical optical imaging does not imply interdisciplinarity. Rather, the field is engaged in solving “known unknowns”,

\textsuperscript{66} SINAPSE website, online at http://www.sinapse.ac.uk/about-us-1/theme-leaders [Last accessed 25/08/2022].
\textsuperscript{67} MDPI website, online at https://www.mdpi.com/journal/diagnostics/topicalcollections/Medical_Optical_Imaging [Last accessed 25/08/2022].
as depicted in Osborne (2013). Supervisors set research projects that fit in their programmes, where the topic is a known problem, and students work to produce answers to what is not known. A fictitious example project from CDT-OPTIMA would be the characterisation and behaviour of specific cells in a given type of cancer. The unknown problem in this example could be how to better diagnose and/or treat the cancer through a deeper understanding of the particular cells that is to be obtained by the students using medical optical imaging techniques. In this context, the organising unit of research is not a scientific discipline but a knowledge object that is, as yet, incomplete and unfolding in an object-oriented practice (Knorr-Cetina, 2001, p.185). The practices involved here necessarily demand sayings and doings or competences and materials from various methods and theories found in the disciplinary foundations of the field: I would imagine at least an understanding of the disease, of the cells, of an imaging technique, and of chemical processes. Whereas the policy push for interdisciplinarity has seen the flourishing of doctoral training across several disciplines, it is clear that what is required here is training to identify and use the suitable tools, materials, equipment and know-how to arrive at a solution to form the knowledge object more completely. Following the idea of classification, as discussed above in section 8.3, defining a doctoral programme as interdisciplinary allows students to differentiate themselves from other students and to (re)produce ideas of what interdisciplinarity is based on their experiences and, thereby, construct different versions of interdisciplinary training. For the present study, I will argue next that the concept of
“bricolage” points to the practices of CDT-OPTIMA students as being a type of informed interdisciplinarity, which is itself disciplinary in nature.

**Bricolage**

Reflecting on efforts to link economics and politics in policy analysis, Easton (1991) remarked that “this combination seems to remain just an assembly of large pre-existing bits and pieces, only a tiny fraction of the contents of the underlying disciplines.” Easton’s remark is similar to the term bricolage, understood in qualitative research as practices that incorporate the knowledge and expertise of diverse disciplines and employ a wide range of tools (Yardley, 2019).

Assembling bits and pieces resonates with the findings of this study, as opposed to issues of integration of knowledge (discussed in section 2.2). This practice resembles what Lattuca described as “informed interdisciplinarity”:

> In research, disciplinary questions may be informed by concepts or theories from another discipline or may rely upon methods from other disciplines, but these disciplinary contributions are made in the service of a disciplinary question. (Lattuca, 2001, p.82)

In her extensive empirical research on participants’ understandings of interdisciplinarity, Lattuca (2001, p.79) found that although this type of research is constructed as interdisciplinary, it is, in reality, more disciplinary in nature. In agreement with this finding, I suggest that because interdisciplinarity necessarily involves a transformation of disciplinary
knowledge and results in “more than the sum of its parts” (Lyall et al., 2011b, p.14), the type of research involved in CDT-OPTIMA is disciplinary and located in the field of medical optical imaging, which is an emerging interdiscipline. In other words, the disciplines involved in optical imaging interact to arrive at an end product (be it knowledge or innovation) but are not changed at their core. This finding is consistent with a growth of research that shows interdisciplinarity in practice is different from how it is actually talked about (for example, Mäki, 2016) and points to a more general confusion among government, universities and researchers as to what type of knowledge is sought and valued.

Assembling disciplinary “bits and pieces” amounts for some scholars to “appropriation” of tools and methods across disciplines (Forsythe, 1999; Silvast and Foulds, 2022a, p.43), “parasitism”, “imperialism”, “trespassing” or “poaching” (Osborne, 2013), “assemblages” (Fenwick and Landri, 2012; McFarlane and Anderson, 2011), “borrowing” (Klein, 1996, p.62), or bricolage (Papson, 2013). All these terms would imply knowing where concepts and methods are located, in which discipline, and thus further implies strict separate entities and constitute an essentialist view of disciplines. This type of discourse is somewhat surprising for me, considering the now-established view that disciplines are not as bounded or isolated as once thought, yet, in order to discuss this topic, I have no choice but to engage in a language that takes disciplines as prevalent. That is perhaps the main point of this discussion: if disciplines are understood from a theory of practice perspective (see section 2.3.5), they represent ways of knowing that are dynamic,
localised and constantly reshaped. Disciplines are most recognisable when understood in their organisational form (historical administrative function and organisation of universities into schools and departments), where they display hierarchical characteristics and bestow power (for example, their role in career progression). Thus, to survive in the university, fields such as medical optical imaging are constituted as units, or discrete entities, where they can flourish without disturbing the institution. In practice, disciplines are social institutions with flexible boundaries that allow practitioners to combine them into interdisciplinarity. I believe proponents of a “new world of interdisciplinarity” confuse the disciplinary organisation of universities with the evolving research practices that take place within and that consistently seek to push society’s knowledge further.

Describing interdisciplinarity as “new” exposes it to criticisms and ideas that it is a “fashion” or “fad” (Goodwin, 2006; Osborne, 2013) and that everyone can “be” interdisciplinary in the same way that anyone can be a social scientist (Forsythe, 1999). This description leads to problems of classification (Bowker and Star, 2000) where interdisciplinarity comes to be understood in opposition to disciplinarity, takes the form of multiple metaphors such as the chimera described earlier (section 8.3) and where students are seen to occupy a space of marginality. Yet, thinking about a field of research as an interdiscipline dispels all these myths because it makes visible the disciplines involved and why they are used together.
8.3.2 Interdisciplinarity as an ideological driver

Interdisciplinary practices often produce a certain kind of knowledge: knowledge for action based on the context of problems to be resolved; it is often collaborative (sometimes involving non-academic participants), and, importantly, this knowledge bears no allegiance to a particular discipline. This type of knowledge poses serious challenges for academia: it is not easy to measure “interdisciplinarity” (Wang and Schneider, 2020), there is often a disconnect between how interdisciplinarity is described and how it is practised (Mäki, 2016), it may be more ideological than practical (Allen, 2017) leading to exaggerated promises and unrealistic expectations (Graff, 2016), and the quality and outcomes of interdisciplinary research have been questioned (Frickel et al., 2016, p.12). In their extensive research on interdisciplinarity in the UK in 2005/6, Griffin et al. (2006) reported a lack of scientific credibility because it does not fit the university model - it lacks status and is sometimes not perceived as serious (p.61-62). These debates serve as examples of the multiple issues and concerns within universities, but they are often talked about without reference to the role of scientific knowledge in society, a sharp contrast with many definitions of interdisciplinarity as knowledge production to solve societal challenges (Klein and Newell, 1997), which is what I focus on next.

I would argue that another issue concerning interdisciplinary knowledge is its construction as “science for and with society” (for example, as discussed in Scholz, 2020). I find this discourse problematic because it sustains the idea that universities stand apart from society as if they were not social institutions
and an integral part of society. In other words, it reinforces the idea of the university as an “ivory tower” (Shapin, 2012) and students’ views of a distinction between academia and the real world (discussed in section 5.5). When universities are discussed as standing apart from society, it poses problems of who or what society is – users, stakeholders, governments, consumers, participants? (Strathern, 2007) - and frames science and universities as apolitical, as in Scholz (2020, p.1034), who “discusses transdisciplinarity from the view of the university as a (non-political) public good.” I suggest it would be wrong to construe universities, science and interdisciplinarity as purely political, given the academic practices involved in sustaining these systems, but this thesis has shown how politics and policymaking practices influence the direction of research in the pursuit of economic productivity and technological progress. Thus, universities are sites where politics are being played out because they are steered by ideologically imbued policies. Similarly, the ivory tower metaphor conjures up ideas of science that is not always “relevant” to society, which has been shown to be a misrepresentation of science in history (Hessels et al., 2009). However, this is still the underlying message of policies that demand interdisciplinary research. While interdisciplinarity (and transdisciplinarity) are sometimes described as “doing research with or for society”, universities could occupy a stronger position “as a part of a society that does not forever refer back to itself” (Strathern, 2007). This idea resonates with Krause (2020) and her discussion of Barnett’s (no access) “ecological university”, in which universities and external factors are tightly connected. This way of thinking
would need an explicit change in the political discourse that constantly seeks to reassure society that universities are “valuable” and worth investing in.

8.3.3 Interdisciplinary students

The participants in this study felt strongly about their professional identity or lack thereof, especially made visible when they discussed being “the dumbest of the group”, “a jack-of-all-trade”, or “an oddball”. In section 3.3 of this thesis, I noted how students are constructed in UK policies as being in the making towards “proper citizens” for solving Cardwell’s riddle and thus include a specific timescape in which the future hinges on notions of employability and earnings. The notion of learning to acquire a professional identity is thus implicitly connected to the notion of employability in policies where learners become equipped for jobs (Brooks et al., 2022, p.73). The lack of professional identity of interdisciplinary students stands in contrast with the idea of future employment and may partly explain students’ difficulties in positioning themselves as future academics or researchers in industry. Therefore, I argue that interdisciplinary students such as CDT-OPTIMA postgraduates may also be said to occupy a marginal space.

It is common in the existing educational or interdisciplinary literature to find references to “pre-liminality”, “liminality”, “in-between-ness”, and “liminal hotspots” (Beech, 2010; Clinch et al., 2019; Holley, 2017; Meyer and Land, 2005) to describe being suspended between two recognised social roles. From the analysis of my findings in the present study, I believe “marginality”, as described above, is a more powerful concept than liminality: I did not
interpret my participants as being in between roles but, instead, as not belonging fully to a positive reference group, at least compared to other disciplinary doctoral students. It is important to note that marginality and liminality are not mutually exclusive terms, and students can also be described as being in a liminal state. Liminality, understood as being suspended between two recognised social roles/structures (Clinch et al., 2019, p.260), can be applied to any student who is in-between roles, not a complete novice but not yet recognised as an independent researcher. Marginality, in turn, conveys the idea that some individuals do not quite feel like they belong and show ambiguities regarding their roles (Billson, 1988).

This finding supports the idea of academic “homelessness” (section 2.3.3) and of the “academic nomad” that is not anchored by a disciplinary connection (Lyall, 2019b, p.33; Tait, 1999). For individuals who follow a career path in academia, there are plenty of “marginal careers” (Allen Collinson, 2003; Bamber et al., 2017), which are emphasised for interdisciplinary researchers and reinforce the risks of a university career (Gonzales and Rincones, 2012).

Classic academic careers do not typically allow for crossing between different sectors because of the imperative to publish research and produce knowledge. CDT-OPTIMA encourages their “academic nomads” to work for industry in the hope of future opportunities for better collaborations between sectors. However, this makes it harder for students who then hope to stay in academia to forge a career path with a view to obtaining a permanent
Another feature of interdisciplinary doctoral training is the lack of in-depth expertise in a discipline that constrains graduates’ opportunities for teaching, which is also needed to secure permanent jobs in universities (Lyall, 2019b, p.48). Thus, the issue of marginality may add to the problem of growing contract research positions in the UK that contributes to making academic careers appear untenable (Allen Collinson, 2003). The challenges faced by interdisciplinary doctoral students to secure academic positions after graduation and the obtention of a permanent contract were not investigated in the present study, but the issue could be examined through further research.

8.3.4 Disciplines do not talk for themselves

There is, no doubt, ongoing and exciting interdisciplinary work happening in academia where practitioners work together by bringing their disciplinary expertise to projects, but I would argue that caution should still be exercised when qualifying research as interdisciplinary.

Here, I draw on papers from McMurtry (2011) and subsequent reply from Barnett (2011), explicitly referring to both authors’ attempts to elucidate whether interdisciplinarity is the interaction between representatives of disciplines or between the disciplines themselves (while recognising that it could be both). McMurtry advocates the integration of the complexity of phenomena with the complexity of knowers, while Barnett upholds the idea

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68 For example, see the University of Edinburgh website for Translational Healthcare Technologies (THT), online https://www.ed.ac.uk/inflammation-research/research/translational-healthcare-technologies [Last accessed 28/08/2022].
that interdisciplinarity is a symptom of the liquid state of knowledge and modernity (citing Bauman, 2000; also see Bauman, 2005) and contends there is, therefore, "greater traffic across the disciplines". The idea of traffic in knowledge across disciplines is also noted in Sørensen (2021) in the acknowledgement that disciplines are not autonomous, bounded entities. The idea of traffic across disciplines, if examined through the lens of practice theory, leads me to argue that knowledge does not travel and nor do disciplines interact, thus, disciplines do not talk for themselves. Rather, the idea of disciplines is embodied and carried by practitioners who enact, re-enact, or modify disciplines in practice. This way of thinking brings into light some consequences for interdisciplinarity, two of which I focus on in this section. Namely, from the observations made in this study, I would firstly question whether a single individual can be said to “be interdisciplinary”. Secondly, I interrogate levels of interdisciplinarity in team research and collaboration to show how interdisciplinary projects may tend to result in poor knowledge integration and should be called, at best, multidisciplinary.

The idea of the individual scientist who practices interdisciplinarity seems antithetical to the concept of integration of disciplinary knowledge, but this has not been well-researched in interdisciplinary studies, although the issue has been raised (Fam et al., 2017). Practising interdisciplinarity individually would mean being an expert in at least two disciplines and synthesising or integrating knowledge in a way that results in entirely new knowledge (see section 2.2). Following fieldwork and observation of participants for this study, it is clear that students learn “enough” from other disciplines to arrive
at a solution to their chosen problem, but the analysis shows that even by the end of the programme, students are not as comfortable with some disciplines as with their original discipline, which points to a lack of expertise. This problem is commonly discussed in the literature as a distinction between depth and breadth of knowledge (Carey and Smith, 2007; Golde and Gallagher, 1999). A breadth of knowledge across disciplines does not constitute an in-depth and specialised knowledge of one single discipline, which may take an entire career to acquire (O’Rourke and Padula, 2020). The fact that the participants in this study remain uncomfortable with some disciplines points to the fact that four years of doctoral training did not suffice to acquire in-depth knowledge in an entirely new discipline. The evidence regarding more experienced interdisciplinary researchers seems to point to the same problem. Research carried out by Lyall and colleagues in the UK identified two archetypal groups of interviewees: the “problem solvers” and the “individual careers” (Lyall et al., 2011a, p.18). The “problem solvers” group seeks to work together to integrate and synthesise knowledge to address real-world problems, and the “individual careers” group focuses on working with researchers from other disciplines to improve the individuals’ own research (Lyall, 2019b, pp.24-25). Both groups are seen to engage in collaborative research with other individuals, and interdisciplinary researchers should be “good at bringing people together and making links” (Lyall, 2019b, p.67). The view that collaborative research skills are a pre-requisite for interdisciplinary practice is further reinforced by Holley (2015) in the context of doctoral education. From my own observations and the work of
these scholars, it seems then appropriate to equate interdisciplinary work with collaborative work, which implies that an individual cannot be said to carry out interdisciplinary research. Yet, these same scholars affirm that interdisciplinarity is not always accomplished by teams or collaborative efforts. From the discussion so far, I believe this is due to a confusion with “informed interdisciplinarity”, in which disciplinary contributions are made in the service of a disciplinary question (Lattuca, 2001, p.82). Further examination of this issue is warranted through empirical research to understand what individuals actually do when they say they are interdisciplinary. A good starting point for future research would be the idea that individuals may seek other disciplinary experts to deepen their knowledge of their own discipline because they make use of others’ expertise and help, as discussed by the complacent disciplinarian (Hacking, 2004). What Hacking describes is not the idea of “trespassing”, as discussed in Osborne (2013), where knowledge is taken from another field because of a disciplinary deficit, but rather emphasises that individuals practise their own research with different skills and competences. The complacent disciplinarian is able to draw from others’ skills and competences to enhance their own practices. In my own view, this way of practising research is one that leads to continual learning, respect for other disciplinary insights, and the necessary means and experience to prepare doctoral students for successful interdisciplinary collaborations in the future. Indeed, I see one of CDT-OPTIMA’s strengths in residing exactly in preparing students for future interdisciplinary collaborations, rather than developing interdisciplinary
graduates per se. As I discussed earlier, in section 7.2, this is also one of the major problems with the programme that I interpret as lacking the necessary collaborative networks to achieve this aim more efficiently.

While I have suggested that interdisciplinarity is by nature collaborative, I am not making the case that all collaborations are interdisciplinary. This fact is evident in the earlier discussion of optical medical imaging as an interdiscipline and is also a reflection of the growth of cross-institutional consortia\(^69\) that are collaborative alliances between universities' departments in the same fields of research, as indicated by their names and that may amount more to a strategic pooling of institutional resources than interdisciplinarity (even though, obviously, it does not preclude scientists within these consortia from being involved in interdisciplinary research).

The idea of greater traffic between disciplines and the need for collaborations to perform interdisciplinarity bring about the second issue I set out to discuss in this section. Because disciplines are performed and enacted by practitioners, setting up contexts for interdisciplinary work, such as collaborative projects, does not necessarily result in interdisciplinarity either. Contexts are also enacted through the practices of practitioners who must be willing to learn from each other, share their expertise and contribute equally to the project. While there are recognised benefits to participating in

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\(^69\) For example: ScotChem, online at [https://www.scotchem.ac.uk/about/](https://www.scotchem.ac.uk/about/) [Last accessed 29/08/2022]. SAGES, online at [https://www.sages.ac.uk/](https://www.sages.ac.uk/) [Last accessed 29/08/2022]. SISCA, online at [https://www.sicsa.ac.uk/](https://www.sicsa.ac.uk/) [Last accessed 29/08/2022]. SUPA, online at [https://www.supa.ac.uk/](https://www.supa.ac.uk/) [Last accessed 29/08/2022]. MATS, online at [https://masts.ac.uk/](https://masts.ac.uk/) [Last accessed 29/08/2022].
collaborations, such as the advancement of knowledge, obtaining grants, and publication counts, there are also undoubtedly costs to collaborative work (Leahey, 2016) in terms of efforts required. Such costs, or additional burdens, were observed during the study of CDT-OPTIMA students in their relationships with their supervisors and the travel involved between two Scottish universities. Time is a cost, both in collaborative work and interdisciplinary doctoral training, because it falls on students to manage their supervisors’ expectations. Since supervisors are experts in one discipline, students spend much time explaining the other parts of their research that are from other disciplines, have to remind supervisors that their research goes beyond their disciplinary interests, and often have to explain how disciplines are used to arrive at the end result. Fortunately, some supervisors were previously involved in interdisciplinary research and are already aware of the difficulties students encounter in terms of learning new disciplines, but there is still a sense, from what students told me, that they need to “educate” their supervisors. Time is also spent travelling between universities or between sites. While CDT-OPTIMA students welcomed the opportunity to (re)engage with their peers, travelling was sometimes described by the participants in this study as wasted time when experiments were in place in laboratories and the students were absent and unable to monitor or obtain data. These issues are not well factored into the programme and can be a hindrance to the progress of students who already have to manage their time carefully considering the multiple activities involved in a doctorate, such as skills development courses, tutoring, and seminars in addition to performing
research. It is widely recognised that working across disciplines takes time and requires “spaces” to develop the skills necessary to communicate with a wide range of colleagues (Lyall, 2019b, p.79). CDT-OPTIMA students have no choice but to spend time travelling to meet with other students in their programme or to take business courses. Space and environment play a major role too. As students are scattered around different sites in two different cities, multiple hospital settings and labs, problems of isolation are accentuated. The need for developmental networks for interdisciplinary learning (Baker and Lattuca, 2010) and the lack of opportunity to interact with mentors identified by CDT-OPTIMA students (section 7.2.5) point to opportunities for interdisciplinary doctoral programmes to enhance students’ experiences. Interdisciplinary programmes would be more effective when providing sufficient collaborative networks for students, not only to discuss their research informally and develop their communication skills but this would also help them feel better integrated and perhaps less isolated.

### 8.4 Interdisciplinarity as an investment

The UK Government is faced with the complex task of finding possible solutions to Cardwell’s riddle to make the UK a global science superpower (BEIS, 2021, p.16), not only to address grand challenges such as healthcare and climate change but also for international economic competitiveness (Pfotenhauer et al., 2019). The riddle (section 3.2) – how to make the UK economically competitive through scientific innovations - is predicated on an essentialist view of technology and innovations as the pillars of prosperity, themselves reliant on the continued growth of knowledge stock from
researchers (UK Government, 2021a, p.10). Aside from research organisations, the largest stock of researchers is to be found in academia, which is also the greatest provider of trained research professionals. Thus, a way to solve Cardwell’s riddle is to incentivise existing researchers and train new ones to produce knowledge that can be translated into innovations and commercialised.

Higher education is a vast, global industry (Wolf, 2002, ch.1), commonly thought to improve standards of life and economic productivity worldwide (Taylor, 2016, pp.40-41). Governments insist that in a “knowledge-based economy” (BIS, 2016), universities are engines of growth for science and innovation, and the modern era is characterised by: the massification of student numbers at universities (Altbach, 2017), the rate of growth of knowledge production and a strengthening of knowledge applied to economic ends (Temple, 2012). Accordingly, the UK has made strategic investments in its research and development system to catalyse scientific research to deliver rapid and revolutionary advances in many areas, including healthcare treatments and technologies (Aarden et al., 2021; UK Government, 2021a). In this context, the education of a highly skilled workforce is deemed necessary to “attract, develop, and retain enough people […] to meet this ambition” (BEIS, 2021, p.5).

In its pursuit of innovation, the UK Government set out their vision of how this skilled workforce is to achieve the translation of scientific knowledge into technology for a prosperous nation. In particular, the idea that students
should be trained to work in teams and collaborations is strongly associated with how academia should deliver policy strategies. For example, when CDT-OPTIMA was set up, EPSRC’s vision was for CDTs to “provide a supportive and exciting environment for students, creating new working cultures, building relationships between teams in universities and forging lasting links with industry” (EPSRC, 2018). It seems essential, in policy at least, that researchers can deliver innovation and develop their own careers and that to do so involves the movement of people across sectors and interdisciplinary research (UK Government, 2020, p.21). Thus, interdisciplinary doctoral training is seen as an essential skill for a “profound understanding of the interfaces and differences between sectors” (UK Commission for Employment and Skills, 2014, p.27). It is clear the government continues to conflate collaborative research with interdisciplinarity, and some of the reasons for this push are to be found in the Report of the Medical Imaging Technology Working Group (EPSRC and MRC, 2012): links between researchers and industry will allow access to novel ideas, to people trained in specific techniques, and better synergy of expertise between academia and industry (p.6-7); collaborative links will keep the workforce “agile”, thus cutting down on slow recruitment processes (p.7), by creating a “critical mass” of individuals able to work collaboratively for international competitiveness (p.11); and for equipment sharing for the NHS (p.13). This idea of networking and collaboration between sectors interprets innovation as an interactive process and “an outcome of interactions between a multitude of actors, distributed over many different institutions and locations.”
(Doloreux, 2002). The evidence of cross-sector partnership is found in CDT-OPTIMA’s grant proposal showing that industrial partners are embedded in the programme and offering their support for possible collaboration through letters of commendation.

It can therefore be said that the introduction of strategic interdisciplinarity (Tait and Williams, 1999) in government policies is based primarily on the perceived benefits of strengthening universities’ relationships with industry and stands entirely outside the internal workings of academic research and knowledge production. This insight strongly contrasts with scholarly concerns about how to define interdisciplinarity as an internal process of research (even when non-academic stakeholders are involved). This view, and its consequences, are examined in detail in the following section.

8.4.1 The triple helix

Flows of interactions between universities, industry and government, or the triple helix model (see section 6.5) are crucial to understanding the challenges paused by strategic interdisciplinarity. This section focusses on two specific relationships in turn: firstly, academia and industry, and secondly, education and policies.

Academia and industry

From a Bourdieusian perspective (Fligstein and McAdam, 2012, p.24; Münch, 2020; Papilloud and Schultze, 2018), universities and industry (or

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70 JeS grant proposal to ESRC for the funding of CDT-OPTIMA – Confidential document.
businesses) represent different fields of practices, and their interactions can create opportunities or crises. Obviously, scientists have had a long involvement with putting knowledge to use in collaboration with other institutions or industries (see Pestre, 2000), but these endeavours are thought to be confined mainly to the actions of individual scientists with entrepreneurial dispositions and a combination of other local factors (Etzkowitz and Webster, 1998, p.37), or simply to explore the range of possibilities of their research for new or improved technologies or the applicability of their research to concrete situations (Marcovich and Shinn, 2012). Overall, formal mechanisms to link universities and industry have been shown to have little effect, and linkages are primarily personal rather than institutional (Hughes, 2011). Efforts to establish connections between the two sectors through graduate students have not been well researched empirically but are thought to be worthwhile pursuing in policy where doctoral students have more freedom to pursue their creativity and “explore areas that would otherwise be considered too risky for other funding opportunities” (EPSRC, 2021, p.4). Such efforts have resulted in suggestions that students’ role may be that of tokens of exchange between academe and industry (Slaughter et al., 2002).

Institutions and professions have historically evolved through a process of boundary work and demarcation practices in pursuit of authority and material resources and to exclude rivals and outsiders (Gieryn, 1983). Thus, academia and industry represent different sectors with conflicting interests, knowledge on one hand and capital accumulation on the other hand. The UK
Government’s focus on processes to connect both sectors remains contentious and challenging (Münch, 2020) and necessitates close monitoring. For instance, the latest report on universities and business links in the UK provided by the National Centre for Universities and Business (2021) found that although research commercialisation is growing, “the number of interactions between universities and businesses, particularly SMEs, fell” (p.75).

Academic practices reflect researchers’ and institutions’ struggle for position and prestige and the accumulation of scientific capital, especially through research publications (Münch, 2020). Industry and business practices are concerned with trade secrets, as Ochs (1985) put it, or nowadays, patents and the use of knowledge to derive profitable products and services. Thus, the practices of academia and industry may come in tension between, on the one hand, knowledge as a collective good for the scientific community and, on the other hand, knowledge for innovation and capitalism (Münch, 2020).

The concept of circulation of knowledge between different fields and sectors (Marcovich and Shinn, 2012) is powerful in this context for understanding cooperation between researchers and industry. Marcovich and Shinn (2012) demonstrated that a transversalist perspective of science enables the consideration of a federative system of science that considers the individual characteristics of the sciences. They argue four regimes of science production and diffusion exist, each the product of their own particular historical circumstances: the disciplinary regime, the utilitarian regime, the
transitory regime, and the research-technology regime. These regimes are pertinent for the present study since CDT-OPTIMA students are required to work with external stakeholders (section 1.3.2) and train to become scientist entrepreneurs at the interface between academia and industry. Figure 15 summarises my understanding of these four regimes:

<table>
<thead>
<tr>
<th>Regime</th>
<th>Aim</th>
<th>Referent</th>
<th>Boundary-crossing?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disciplinary</td>
<td>Research outputs for disciplinary peers</td>
<td>Discipline</td>
<td>No, borders remain intact even in collaborations</td>
</tr>
<tr>
<td></td>
<td>Feeds on itself</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilitarian</td>
<td>Produce goods/services for client</td>
<td>Economy</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>External factors</td>
<td></td>
</tr>
<tr>
<td>Transitory</td>
<td>Advance research and serve practical purpose</td>
<td>Discipline first, enterprise second</td>
<td>Yes, but infrequent, not repeated or regular</td>
</tr>
<tr>
<td>Research-technology</td>
<td>Extend science and technical work</td>
<td>Instrumentation</td>
<td>Yes, circulation is crucial</td>
</tr>
</tbody>
</table>

*Figure 15: Four regimes of science production and diffusion*
*Author’s summary of Marcovich and Shinn (2012)*

Boundary-crossing, in this perspective, does not refer to disciplines but to borders between sectors (academic and industry/business). The case of CDT-OPTIMA would, thus, be classified as a regime of research-technology where Marcovich and Shinn (2012) focus on instrumentation or instrument-related endeavours as the primary referents of the research-technology regime, whereas in this thesis, I also refer to services as well as products. By products and services, I mean any innovation from which the healthcare system may benefit (including new techniques, new objects of research, and
technology). This regime focuses on the “circulation of practitioners, materials and ideas across boundaries within science and between science and other sectors” (ibid. p.58).

I would argue that the concept of circulation is rarely articulated in the existing research on interdisciplinarity, with the exception of Darbellay (2012), and is ill-defined in policies. As discussed earlier, policies have identified the need for the movement of people across sectors, which seems to be conflated with interdisciplinarity, but that is quite different in terms of what travels across boundaries and what these boundaries represent. In interdisciplinary collaborations in academia, boundaries are demarcated by disciplines (section 2.2), but in academic-industry collaborations, boundaries exist between sectors and their differing interests, as discussed earlier in this section. A researcher in the research-technology regime works in the interstitial arena that exists between institutions. As opposed to the utilitarian regime, the researcher does not work for a client or to a client’s requirements and thus provides a “temporal space relatively free from exogenous constraints” (Marcovich and Shinn, 2012) in which research activities are carried out freely but still with a view for future applicability.

Collaborations across university researchers and industry are challenging because actors relate to different institutional logics based on social (or academic) capital in universities and on material capital in firms (Steinmo, 2015). Increasing the movement of people across sectors is a complex problem that should take into account the practices that enable the

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successful circulation of people, materials and ideas. In 2021, the UK Government saw a fall in the number of interactions between universities and businesses (National Centre for Universities and Business, 2021, p.75) and continued to pursue efforts to strengthen interactions. In fact, such efforts sustained over the last few decades have been shown to have had little effect on UK university-industry interactions, which are also discipline-dependent (Calvert and Patel, 2003).

Research into students’ experiences of crossing between sectors during their PhD training shows no evidence of a smoother transition to industry employment (Germain-Alamartine et al., 2020), but can be an asset for students’ careers in industries that require staff with research training (Thune, 2010). In terms of doctoral training, students’ border-crossing activities between sectors could be made more efficient if they were integrated into a curriculum that defined the purposes of such activities. Specifically, the work placement component of CDT-OPTIMA might benefit from a focus on the educational dimensions affected by the interactions between sectors instead of being used as a career development tool. On the basis of the data gathered in the present study, the concept of interdisciplinarity was not found useful in the analysis of student and industry interactions (even when it is taken to be synonymous with collaborations) because it fails to emphasise the need for a shared social experience between individuals based on cohesion and convergence between science’s regimes. On the basis of the data gathered, I believe it is possible and a requirement that students understand the disciplinary regime of science, to which they contribute by
generating knowledge and to the other regimes and their different work processes, objectives and values (Marcovich and Shinn, 2012). Until then, academia may still be viewed by students as the “ivory tower” and industry as the “real world”, with little linkages between these two spheres in terms of how they interact and how they are involved in bringing about technology and innovations together for translational science.

The UK is currently well-equipped to promote the circulation of people and knowledge across sectors, with many efforts involved in the health sector, which is relevant to CDT-OPTIMA. The rationale behind such efforts could be better articulated in doctoral programmes to reinforce the idea of collaborations, how students can engage in programmes and to start building their own networks and careers. For example, Scotland has recently seen the formation of Research Innovation Scotland: https://www.research-innovation-scotland.co.uk/, which seeks to pool research for collaborations across sectors, and the UK-wide body Innovate UK (part of UKRI) includes a Knowledge Transfer Network (KTN) Health programme that seeks to connect business, government, funders, research and the third sector: https://ktn-uk.org/about/. Opportunities to integrate various sectors could be seized at the postgraduate stage of researchers’ training to reinforce the idea that students have a major role to play within this research and development system, to develop a better sense of belonging and to break down the dichotomy between the academic and the real world. In essence, this would largely contribute to a better understanding of interdisciplinary practices by emphasising the material-economic and social-political arrangements to build
on the practice architectures of university education as described by Kemmis and Mahon (2017) and discussed in section 2.3.5. From the perspective of academia and research funders, this could give a possible answer to the question of which experiences should be provided by doctoral education (EPSRC, 2021, p.12) and the chance to align a portion of the educational process with national research and innovation policies to the benefit of “UK plc”. Such recommendations have already been articulated in the existing research on translational science, for example, by Gill et al. (2015), but rely on further commitment and efforts from academic staff who are not rewarded for such efforts and, perhaps, not best placed to deliver such initiatives considering the difficulties encountered in team-teaching and finding enough and the right mix of competences.

**Education and policies**

In this thesis, I have already discussed the UK Government’s policies and visions that interdisciplinary doctoral education is expected to address and achieve (chapters 3 and 6). The data analysis sections showed a strong concern with the “future” from governments, universities and students, constructed along particular imaginaries. In this section, I propose to problematise the notion of sociotechnical imaginaries (Jasanoff, 2015b) in education to understand the relationship between academia (and students) and the UK Government and how they gave rise to a policy push for interdisciplinarity. This perspective was chosen following particular insights during the research:
- Efforts to define interdisciplinarity and its effects on higher education are now decade-long and remain unanswered (see Kockelmans, 1979).

- Debates continue to animate academia as if interdisciplinarity was an inevitable part of research and education without questioning the underpinnings of policies or their consequences (Albert et al., 2019).

- A belief that education is an integral part of political visions that create certain futures and is, therefore, based on sociotechnical imaginaries. This perspective agrees with the argument from Rahm (2021), who notes that education as sociotechnical imaginary is often overlooked.

Interdisciplinarity is always associated with progress in policymaking that seeks to solve the issue of attending to the future by creating desired futures that include economic growth. Governance becomes the task of creating a body of ideal researchers (Rahm, 2021); in the case of the present study, the “proper” scientists of the future are workers for the biotechnology science-based business (Pisano, 2006, p.2) and the health bioeconomy (Mittra, 2016). Educational policy intends to address the problem through investments in new models of doctoral training programmes, such as interdisciplinary doctoral training in CDTs. Through the examination of CDT-OPTIMA, the present study has identified many positive outcomes of interdisciplinary doctoral training but also many challenges in this way of thinking and governing, particularly with practices of causally linking variables in the R&D system. Despite many criticisms of the linear model of innovation (section 6.4.1), assumptions of linearity continue to dominate policy rhetoric.
underpinned by the identification of “gaps” in the translation of basic knowledge into innovation, that will be bridged by translational science (Mittra, 2016, p.62). By the same token, it is easy to see how a linear model of governance is present in current UK educational policies that seek to train the ideal future researcher from student to interdisciplinary researcher, to collaborator, to innovator and to entrepreneur, as is found in CDT-OPTIMA model. In this model, gaps reside in the capabilities of researchers, or their inability to translate knowledge into innovation, and thus, ignores scholarship as the primary mission of universities (Lauder and Mayhew, 2020). By introducing a linear logic to the production of innovation and researchers, policies redefine academic practices beyond the realm of higher education and inside the boundaries of the business system (Pisano, 2006, p.1).

The science-based business of biotechnology seeks to create knowledge and derive economic returns from it (Pisano, 2006, p.2) and, therefore, holds a promissory value in policymaking (Mittra, 2016, p.5). These promissory values can be economic (revenue, employment, reduction of costs) or non-economic (advancement of knowledge, health benefits to society, legitimacy of political decisions). However, in the policy literature reviewed in this thesis, there is often a tendency to “hide” the expected economic returns of biotechnology and doctorates in the field through recourse to concepts of employability, prosperity, and investment when talking about students. In other words, students should invest in such doctoral programmes (time and money) for future employability in highly skilled jobs (high earnings), and they will therefore prosper (and help the country prosper too). Unfortunately, in
their in-depth studies of the promises of education, Brown et al. (2010, p.148) concluded these promises were “broken” and instead delivered widening economic divisions, high skilled and low waged workers, and, more generally, that connections between education, jobs, and incomes have broken down. Discourses of prosperity are often based on an economics view of “human capital” that raises productivity and drives earnings, an example of another “single linear pathway on the complex passage between heterogeneous education and work” (Marginson, 2017). The theory of human capital is detrimental to ideas about education in policy, where it has become “economised” and to students who become “economic resources” (Brooks et al., 2022, p.93). This is not to say that students necessarily identify as an economic resource or as consumers of higher education (Brooks et al., 2022, p.17), but national policies affect social expectations about higher education, why students choose to enrol on a doctoral programme, or why credentials are important in labour markets (ibid. p.101). Fortunately for CDT-OPTIMA alumni\textsuperscript{71}, their current profiles indicate a large proportion of graduates in employment after graduation, with many staying in positions at universities. However, job descriptions range from shop manager to scientist, science communicator, advisor, analyst, etc. Despite some data available on post-graduation destination of CDT-OPTIMA students (see footnote 12), further research could shed light on whether their PhD programmes have delivered the students’ expectations for the job market in the longer term. Interestingly, so far, two students describe their post-graduation roles as translational

\textsuperscript{71} CDT-OPTIMA Alumni, online https://www.optima-cdt.ac.uk/alumni/ [Last accessed 11/08/2022].
scientists, and this pauses the legitimate question of whether CDT-OPTIMA has been successful in delivering entrepreneur scientists for technological progress. Again, this issue could be examined through future research to examine the long-term effects of education on the R&D ecosystem and the longer-term career paths of graduates.

What is clearer from this analysis is that biotechnology has been partly used to change educational practices and modes of working by setting out the government’s policy expectations for the future, whether this future is achieved or not.

The future remains unpredictable, and attempts at steering students’ careers in certain directions could lead to false hopes (Williams, 2006, p.265), especially since high-skilled careers are not always available in the job market. This issue is discussed further in section 8.5.

8.5 Creating futures with sociotechnical imaginaries

The promotion of interdisciplinarity can be directly linked to the objectives of the UK Government and policies that equate this mode of knowledge production with collaborative work, circulation of people and knowledge across sectors and technical progress. Policies and politics construct specific visions about possible futures (UK as a science superpower) from expectations about scientific research (innovations and economic productivity) that promise benefits for all in society (healthcare in the context of the present study, employment, economic power). As briefly described in section 6.1, this phenomenon results from the production of sociotechnical
imaginaries as described by Jasanoff and Kim (2009) and later refined in Jasanoff (2015a). Put simply, sociotechnical imaginaries are collectively held imaginaries and visions:

…that integrate futures of growing knowledge and technological mastery with normative assessments of what such futures could and should mean for present-day societies. (Jasanoff, 2015a, p.337).

Sociotechnical imaginaries are a possible explanation for how interdisciplinary practices have become an international phenomenon: it is not the case that practices somehow “travel” between institutions and countries, but rather, sociotechnical imaginaries circulate to new locations where they can “take root and flourish in new soil” and are re-embedded in new practices (Jasanoff, 2015a, p.333). In a globalised world (Miller, 2015), science and technology are increasingly central to competition and imagined to increase the wealth and well-being of societies. Countries respond differently to this challenge (Taylor, 2016, ch.1) and adapt their practices, politics and institutions accordingly. Such an example can be found in the concept of the “knowledge economy” and its emphasis on learning and the production, distribution and use of knowledge (Foray and Lundvall, 1996, p.12). The knowledge economy is an enduring concept in the UK political discourse, such as Success as Knowledge Economy (BIS, 2016), and is also promoted worldwide through the work of the OECD (Godin, 2006b; Mangabeira Unger, 1996) and in Europe underpinned the Bologna Process of 1999 (Barrett, 2017). In the UK, this so-called knowledge economy has driven universities’ expansion, the idea of a highly skilled workforce, and the
imaginary of learning = earning (Lauder et al., 2012, p.7). Yet, research into occupational data has revealed the “United Kingdom’s economy is far from being that of a KBE” (knowledge-based economy), and the graduate labour market is not increasing in line with the supply of graduates (Brown et al., 2004) and continues to reproduce educational and labour market inequalities (Brown and Souto-Otero, 2020).
Chapter 9  Concluding reflections

This concluding chapter summarises the key findings of this thesis from a reflexive stance on the processes of carrying out the research, including a list of recommendations, limitations of this study, and issues for future research.

The fact that interdisciplinary research is currently being promoted as the potential answer to many complex problems led me to investigate what is explicitly meant by the term *interdisciplinarity* in two distinctive UK contexts: interdisciplinarity in policies and politics, and its practical enactment in a centre for doctoral training. This exercise has shed light on the diversity of understandings associated with interdisciplinarity both between the university and government sectors and within academia. I have argued that amongst the confusion, interdisciplinarity may be likened to a “chimera”: a mythical creature composed of different body parts (see section 8.3). From this perspective, I have shown how students engaged in interdisciplinary doctoral training can be understood as occupying a space of marginality that reinforces the view that interdisciplinarity is not the norm in academia. Yet, doctoral students’ voices and accounts of their own experiences are largely absent from the existing literature on interdisciplinarity, even as more graduates are enticed into interdisciplinary doctoral programmes.

Students, such as the participants in this study, actively choose to embark on interdisciplinary studies, often motivated by the novelty of such programmes and exciting prospects for their future careers. These scientists in the making
embrace not being constrained by the disciplines, widening their horizons and are articulate about the robustness of their training and the many skills they develop during their educational journey. However, such enthusiasm for interdisciplinarity eclipses many difficulties students encounter in their disciplinary-based university. The interdisciplinary chimera is problematic for political and higher education institutions, which seek to fulfil dissimilar ambitions while aiming to satisfy the objectives of their many stakeholders, be they social, political, or economic.

The journey during my own doctoral training reflects, in a sense, the experiences of the students who participated in this study. I had no conception of the term *interdisciplinarity* at the outset of my research, except for the vague instinct that, in research, the concept points to the use of two or more disciplines. It is through this study that I became aware of multiple nuances – for example, between multidisciplinarity, interdisciplinarity and transdisciplinarity – and of multiple practices involved behind such concepts. From this perspective, my experiences have been very different from my participants’ and showed how strongly issues of situatedness and positionality affected my understanding of my own and my participants’ experiences of the doctorate and ongoing identity work. For example, while I have drawn on multiple research fields and disciplines in the making of this thesis, I have benefited from an academic “home” in Science and Technology Studies and underpinning expectations for interdisciplinary work, the availability of role models and experienced mentors in this type of research. Nevertheless, I had to look outside of STS to draw on educational research.
as an underpinning concept. The similarities and differences between myself and my participants, thus, point to the crucial role of reflexivity in research and its ability to illuminate the intricacies of qualitative studies, especially when researching one’s own institution. These intricacies are not unique to this research and especially not STS scholarly work, but are often left unarticulated, setting researchers’ practices apart from the research itself.

From a theory of practice perspective, as used in this study, I have come to particularly appreciate the importance of, and question, my practices in terms of growth as a researcher, my values and position towards the social mechanisms through which knowledge is produced, and how the idea of the university is reproduced through multiple academic practices. I do not claim here to have detailed all the academic practices undertaken during this project - this is not an auto-ethnography - although this exercise may be valuable to other students and may be the subject of further publications. However, I wish to acknowledge my responsibility in producing a (partial) interpretation of interdisciplinary doctoral training from a specific point of view, point in space and point in time, as inspired by Bourdieu (2004) and his Sketch for a self-analysis. The participants in this study also contributed from their positions on very specific points in their educational journey, and I believe that together we have co-created a “space of possibles” (Bourdieu, 2004, p.97) – a space that could be given all our possible positions. This insight has strongly influenced the writing of this chapter.
9.1 Contributions from this study

This study investigated how interdisciplinary doctoral training is enacted in practice in a specific centre for doctoral training and the policies underpinning the growth of interdisciplinary PhD programmes in the UK. In doing so, this research contributes to the interdisciplinary and educational fields by providing empirical evidence of students’ experiences, which have, so far, been insufficiently reported in the literature, as discussed in section 2.3.2. Firstly, theoretically, this study has employed a practice theory perspective to make explicit how interdisciplinarity is enacted by the participants of CDT-OPTIMA. While practice theory has previously been used in educational research and STS, very few scholars have identified the potential of this perspective in their discussions of interdisciplinarity. Secondly, the methodology used for the data analysis is rarely acknowledged in the existing literature, although the use of mapping has long been shown to be a valuable tool for learning, understanding connections and finding gaps (section 4.6). Thirdly, this thesis has shed light on aspects of interdisciplinary doctoral training not previously identified in research by establishing connections between interdisciplinarity, doctoral training and practice theory. The literature to draw from was vast, but the present thesis curated and synthesised a contextualised body of knowledge that specifically provided a deeper understanding of interdisciplinary doctoral education. Essentially, this thesis can be read as an interdisciplinary piece of work but one that is different from the work of the students under study. This research is, in my view, a case of informed interdisciplinarity (section 8.3.1), where I have used
different disciplinary insights to strengthen and contribute to knowledge in my home discipline – science and technology studies. The following sections summarise the findings of this thesis and how they contribute empirically, methodologically and theoretically to current understandings of interdisciplinary doctoral training.

9.1.1 Empirical contribution

The analysis of key strategic policy documents has shown the important rhetorical role placed on interdisciplinarity through the lens of sociotechnical imaginaries (section 8.5). Interdisciplinarity is on the rise worldwide, and many countries rely on this type of knowledge production in the belief that it is potentially superior to disciplinary knowledge for finding solutions to complex societal problems and boosting technological progress for economic growth. Using the concept of sociotechnical imaginaries has highlighted how much the policy rhetoric around interdisciplinarity and doctoral training is, in fact, based on promises and expectations for the future. Policies have created powerful social imaginaries in order to maximise interdisciplinary knowledge production in universities in the interests of their own political goals. For example, the “knowledge economy” and “UK Plc” require scientific research to be relevant, impactful and translatable into innovations to bridge a “gap” between science and industry. As argued in section 2.1.1, academia has always been responsive to the needs of society, and the idea of a gap is not entirely convincing, but researchers and universities are steered by UKRI’s funding priorities. However, by proposing interdisciplinarity (mainly in the sense of collaborative research) to bridge this perceived gap, the
government is seen as legitimately solving a pressing problem and can present its vision to citizens by reassurance that solutions to medical problems are being investigated and forthcoming, as in the case of this study. The complex problems interdisciplinarity is thought to contribute to are scientific issues that are legitimised through the government’s requirement for knowledge that should be more useful and represent value for money. This problem has already been discussed in the interdisciplinary literature that often points to the scientification of politics and the politicisation of science (Weingart, 1997), and the commodification of research (Hoelscher, 2015). Thus, interdisciplinarity keeps gaining purchase in universities without critical attention paid to its role in society because it is becoming taken for granted that it is the solution to current issues. The assumptions that interdisciplinarity produces superior knowledge and drives innovation are subsequently repeated in policy rhetoric, reaffirming the government’s choice of political strategies and demonstrating their effectiveness in governing the nation, as can be seen in the Build Back Better: Our Plan for Growth report following the COVID pandemic (UK Government, 2022).

The policies and politics of interdisciplinarity stand in sharp contrast to the way universities typically function and are organised. This thesis has briefly traced back the history of UK higher education institutions (section 2.1.1) to show how universities have grown ever more specialised in disciplines and sub-disciplines, which are often identified in policies and academic research on interdisciplinarity as being at the origin of more “gaps”. In academia, interdisciplinarity is often seen as a remedy against the disunity of science
and a way to make disciplines more collaborative, but it is also a powerful marketing tool in a competitive international market. Academics promise more impactful knowledge, a more professionalised workforce, and reassurances to society that science is an endeavour worth funding. Students are told that interdisciplinary training promises a bright future in the job market where they will be able to differentiate themselves from the mass of new scientists through the special skills they will develop during their doctoral studies. The idea of novelty around interdisciplinarity plays a crucial part in the recruitment of students and in what they can expect from their education, but this idea is rarely scrutinised. In practice, as this thesis has argued, students graduate with a poor sense of their professional identity, having undergone many difficulties during their training due to a lack of role models, the dominance of the disciplines within academic careers, and the fact that, as a source of capital, the PhD is being devalued as more and more students graduate and face competition for work. The literature presented in this study (chapter 2) has clearly shown that disciplines are not as disconnected as the imaginary of a “gap” implies, especially not in already established interdisciplines such as biomedicine. Thus, I argue that the idea of novelty, coupled with sociotechnical imaginaries, draws students to interdisciplinary programmes with little attention being paid to the role of PhD students in society after graduation. The UK PhD is the subject of great scrutiny by the government, and the successive reviews discussed in section 3.4, clearly highlight that research training is not considered to be enough or even adequate for future careers, whether in academia or other sectors.
Skills training, internships and work placements are becoming increasingly incorporated into doctoral training to satisfy “employability” requirements stimulating ongoing debates about what doctoral programmes are and how students progress through their career paths (Jones and Warnock, 2015). In this study, CDT-OPTIMA has incorporated business and entrepreneurship skills and work placements into the PhD programme to promote innovative scientists and to forge links with industry. CDT-OPTIMA students have expressed how they have benefited from their training and how they value the presentation and communication skills they have acquired aside from the growth of their scientific knowledge, as well as how much they value the opportunity to experience the “real world” during their placements. However, I argue that graduating with a PhD with integrated studies\textsuperscript{72} fails to signal to any employer the type of expertise they can expect from graduates.

It can be inferred from the present study that the political push for interdisciplinarity is changing the experiences and the self-development of students but that it has little effect on the disciplinary organisation of universities and may, paradoxically, contribute to the further specialisation of academic knowledge (section 6.5). The interdisciplinary PhD remains risky for future careers and produces graduates who struggle to identify with a professional identity required for continued work in a scientific context, regardless of the sector in which they seek employment. Students face multiple possible options for their future career choices, the type of sector

\textsuperscript{72} The official title of the degree awarded by CDT-OPTIMA.
they will seek employment in, and the future they are trying to create for themselves. However, these possible futures risk being colonised by policies that emphasise individual competition and highlight the negative impact this can have on research cultures. CDT-OPTIMA students mentioned a few issues they perceived as negative in the research culture of their universities: the need to constantly seek funding and produce publications, long working hours, unstable careers and how to gain competitive advantage. Beyond academic careers, the future remains unpredictable, and the promises of interdisciplinary doctoral training could lead to false hopes since high-skilled careers are not always available in the job market (section 7.5).

Investigating the interdisciplinary nature of CDT-OPTIMA’s doctoral training, I concluded that biomedical sciences draw on multiple disciplines and that medical optical imaging is an interdiscipline or possibly a discipline in the making (section 8.3.1). Whereas interdisciplinarity is usually understood as broadening one’s understanding of scientific issues, what has been observed in this study is that interdisciplinarity has created a unique specialisation of the students in a “niche” field of research, which essentially amounts to a further fragmentation of the disciplines involved. Specialisation is thus not countered by this type of interdisciplinarity and is, in fact, increasing from the creation of new specialties and approaches. From this perspective, I argue that the political strategies used to enhance collaborations between disciplines in order to address the perceived gaps in research are currently accentuating the specialisation of expertise in universities. This finding concurs with those of interdisciplinary scholars who have previously identified
a paradox of interdisciplinarity: despite ongoing discourses on interdisciplinarity, specialisation and the disciplines are thriving (for example, Weingart, 2000).

9.1.2 Theoretical contribution

My early observation that interdisciplinarity is an academic practice was hardly a major revelation but had an important role in this study and the choice of a theoretical framework within which to conduct the research. “Practice” is an increasingly popular term found in the literature, but the concept is used in more or less inclusive accounts of what has been observed, ranging from a simple term referring to an action to more complex understandings that include processes of learning in specific contexts (Hager, 2012). Practice theory represents a family of theories from which to draw and adapt for the purposes of the issues at hand (section 2.3.4), and a resurgence of practice theorists has been seen in the past two decades, especially in educational research. Because there are different approaches and divergent perspectives in praxeological studies of education, this study has mainly followed the extensive work of Shove et al. (2012b) and Kemmis et al. (2014b) as the best fit for purpose to answer the research questions and aid with the data analysis. The work of Schatzki et al. (2001) is often cited in research as the seminal work that has engendered a renewed interest in practice theory and has also had a strong influence on the present thesis. However, I could not side with Schatzki on the relational understanding of the theory as it was such a crucial issue for my participants, even if I agree that relations are also practices. Similarly, whereas most
practice theorists note they follow a flat ontology, which rejects accounts that privilege institutions, individuals or language (Schatzki, 2001b), I chose to present this study from a multiple ontology perspective, where the “university” is meant as a generic term rather than an entity. Following the work of Mol (2002) on medical practices, a multiple ontology acknowledges that research and training practices within a university, school or discipline are multiple and that the university is more usefully thought of as the university-multiple.

What practice theory has brought to the study is evidenced in its ability to abandon the conventional ways of understanding the world through dualisms such as structure and agency or social and material (Feldman and Worline, 2016, p.2). In this context, disciplines or researchers are not determinants of one another, but they both constitute each other in practice, recognising the possibility that interdisciplinarity can be carried out in multiple ways rather than uniformly. It is also clear from this study that the disciplinary structure of universities can condition or constrain the behaviours of students, but it is also apparent that students are also (re-)producing the idea of the university by navigating the disciplinary landscape. Thus, I conclude that changing the structure of universities, for example, through the creation of interdisciplinary centres, is not a sufficient condition for the institutionalisation of interdisciplinarity, which, if it is to be achieved, will also require institutions to consider resources such as time and access to equipment and shared spaces, and a critical mass of interdisciplinary researchers to serve as role models to students. For interdisciplinary practices to become anchored in an institution, they have to be sustained and repeated through the behaviours of
all involved (management, researchers, students, administration) and importantly, they should not be seen as a challenge or a threat to the established disciplinary practices of universities on which they depend.

**9.1.3 Methodological contribution**

Underpinned by the view that doctoral training and knowledge are social processes, it became important, during the data analysis stage, to devise an appropriate method for dealing with the complexity and vast amount of the data collected. The method of *mapping* in qualitative research can be thought of as a creative way to explore data (Conceição *et al.*, 2017) and was chosen for this study as a way to understand, integrate, and reflect on what I was learning from my participants and from the literature. As well as being a relevant technique for understanding relations between people and processes, mapping was chosen as a personal preference for two reasons. Firstly, attempts to fit in with conventional analysis through computer-aided qualitative data analysis software (CAQDAS) focussed my attention on learning to code text and, thus, interfered with the analytic process (section 4.6). Secondly, as a holder of a diploma in systems practice, my previous educational experiences were based on intensive training in the use of mapping, which had therefore become more instinctual for me. While it is possible to create maps in CAQDAS, mapping manually offered me the freedom to compare the various strands of literature and the perspectives offered by the participants through the iterative-inductive method that requires many iterations and reflexivity (Srivastava and Hopwood, 2009). The present study contributes to the body of literature on mapping for data
analysis by setting out a detailed framework of each step undertaken during the process to highlight the advantages of this method. Moreover, the ability to map my own learning and understanding of the data and literature has allowed me to follow what Patton (2015, p.72) presented as reflexive questions for triangulated reflexive inquiry that takes into account the qualitative inquirer, the participants and the audience.

9.2 Practical recommendations

The higher education sector is striving to remain relevant for the 21st-century society in which it is embedded while retaining its traditional norms and values of scholarship. The interdisciplinary PhD is one of the new models of doctoral training implemented across universities in response to pressures from their many stakeholders (individuals, industry, government).

This doctoral research was never intended as an evaluation of CDT-OPTIMA, but its findings speak to much broader issues within the ontology of interdisciplinarity. Indeed, this study has also identified several difficulties experienced by students, which are summarised in figure 16 as a list of practical recommendations for future UKRI-funded CDTs.73

<table>
<thead>
<tr>
<th>1.</th>
<th>Naming the PhD</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDT-OPTIMA’s “PhD with integrated studies” is unhelpful when students graduate and try to market themselves. Naming their field of expertise with entrepreneurship studies would address the problem.</td>
<td></td>
</tr>
</tbody>
</table>

2. **Interdisciplinarity**

With many definitions of interdisciplinarity, an explicit description of what is expected from students at the outset could help students navigate the sea of expectations they encounter. When working in an interdisciplinary field, as in this study, clearer programme outcomes would help students better identify their expertise (for example, collaborative skills).

3. **Marketing interdisciplinary doctoral programmes**

Attention should be paid with regard to how interdisciplinary doctoral programmes are marketed. For example, this study found participants were steered towards careers in industry, but they should be given the opportunity to pursue their own interests, with paths to postdoctoral positions.

4. **Efforts required from students**

Workloads should take into account the additional burden placed on students by interdisciplinary ways of working. One example would be the amount of travelling involved when PhDs are jointly awarded by two institutions and travel is necessary.

5. **Community**

Interdisciplinary doctoral students require more role models in the academic community to develop their professional identity. This study found that interdisciplinary supervisors are an excellent resource for students, but those who are allocated disciplinary supervisors find it more difficult. Developing expertise at the doctoral level depends on gaining experience with experts, including interdisciplinary experts.

6. **Supervisory arrangements**

Despite having several supervisors, CDT-OPTIMA students often rely on their relationship with only one mentor. This is not helped by the fact that one supervisor is in Edinburgh and the other in Glasgow, making communication difficult and impeding informal corridor communications.

7. **Isolation**

Feelings of isolation, especially when working in labs, are commonplace in doctoral training. Issues are reinforced when students are working alone on projects and struggle to integrate socially into the environment. In this study, participants pointed to the absence of peers and postdoctoral fellows in the labs that
would counter problems of isolation, reinforce the idea of community, and help students with checking their understanding of science while feeling supported.

8. **Institutions**

   In order to institutionalise interdisciplinarity, students and researchers require their work and skills to be valued and rewarded rather than impeding progression into further research. Particular attention to research cultures should be paid with regard to inclusivity, especially towards different ways of knowing, such as interdisciplinarity. Institutions should recognise the value of interdisciplinary researchers and encourage efforts by rewarding these on the same basis as disciplinary expertise.

9. **Collaborations**

   CDT-OPTIMA students would benefit from more (formal) collaborative work. Even though students interact with many different individuals from different disciplines and from invited speakers drawn from business and industry, this thesis has found that interdisciplinary work mainly relies on collaborations. This way of researching could be made explicit during the doctoral programme so students are aware of the specific sets of skills required for interdisciplinarity.

10. **Links with industry**

    In order to forge strong links with industry, students need repeated border-crossing activities. The mandatory work placement required by CDT-OPTIMA mainly serves as a career development tool (for example, students choose their placements in function of their interests and the opportunity to assess the organisational environment in terms of future careers. A focus on the educational dimensions of interactions between sectors would emphasise experiences and reflections on shared social experiences, different work processes, objectives and values.

    The important role performed by CDT-OPTIMA students in crossing borders between sectors should be acknowledged and connected to other initiatives in order to foster more enduring collaborations between academia and industry. Links to Research Innovation Scotland, or other existing networks, would be one such example.

*Figure 16: List of practical recommendations*
9.3 Strengths and limitations of the study

Few studies have, to date, investigated interdisciplinarity in doctoral education, especially from STS and practice theory perspectives. This study has found valuable research and insights from different fields and has contributed empirical evidence, theoretical explanations and has presented a detailed methodological framework for mapping data. This study has illustrated how interdisciplinarity is promoted, both in policy and university circles, often as a taken-for-granted practice. The findings resulting from this research show that the provision of interdisciplinary doctoral programmes is not enough in itself to ensure an interdisciplinary workforce that is guaranteed highly skilled jobs, a close connection between academia and industry, or to ensure technological progress. The participants in this study had quite different experiences with their PhD programmes, depending on the expertise of their supervisors, the availability of peers to learn from and their views on careers. Nevertheless, the participants’ views were presented as a collective picture of some of the challenges encountered during interdisciplinary training, firstly to protect students’ anonymity and, secondly, to reflect the most critical issues found during the research. Overall, CDT-OPTIMA students gained many skills and a lot of expertise from different disciplines during their training, but the overall message from this thesis is that the label “interdisciplinary” is increasingly applied to research and doctorates based on many promises that may not actually be delivered.

This project was undermined by the apparition of the Covid pandemic in 2020 and the inability to continue fieldwork thereafter because of the isolation.
requirements from the UK and Scottish Governments in an attempt to curb the propagation of the virus. The impact of Covid has led to a substantial change in the research design of the project and its focus. Originally, I aimed to contrast the experiences of CDT-OPTIMA students with those of students in interdisciplinary doctoral programmes but not in a CDT. One of the questions this strategy aimed to investigate was whether the CDT model constrains or facilitates interdisciplinary training. Faced with Covid restrictions, fieldwork was interrupted and, instead, refocused on the policy context for interdisciplinarity, which could be researched safely and remotely. Similarly, the research design originally aimed to carry out more extensive interviewing of the participants, CDT-OPTIMA management team, and other researchers and support staff involved in the functioning of the CDT. I was fortunate enough to have immersed myself in CDT-OPTIMA from the beginning of the master’s stage of the project, which allowed me to carry out invaluable work through observations and informal conversations prior to the commencement of the data collection stage of the PhD. This meant that data collection was not as concentrated a process as it might otherwise have been, but on the other hand, the findings from this study were strongly determined by the participants’ perspectives rather than on a focus chosen by the researcher.

A limitation of the study is the situated nature of practices and the multiple cultural configurations of universities and their departments. It does not follow, therefore, that the findings presented here are applicable to the whole university. Readers should be mindful of the context of the research in a
research-intensive university, a specific field of research training and in Scotland. However, the present study sought to offer practical or exemplary knowledge gained through experience, otherwise conceived as “phronesis” (Trowler, 2016, p.10), rather than an ultimate truth, and is in keeping with the theory of practice framework presented earlier. That is, phronesis occurs in the practices of the researcher and may fit or transfer to the reader (Thomas, 2011). Interdisciplinarity is a highly situated practice, but the concept of phronesis enables the possibility that this account can be understood or refuted in readers’ phronesis (ibid.). The transferability of experiences is evidenced in the choice of the literature that underpins this study. The literature drawn on is international, yet many insights and experiences concur, ensuring that results will be meaningful beyond the confines of the present study.

9.4 Directions for future research

Future research may expand understandings of doctoral training and interdisciplinarity in many exciting directions, and qualitative inquiry methods, more generally, may benefit from further testing and refining the mapping methodology discussed in section 4.6.

Empirically, more studies are needed to explore different settings for interdisciplinary doctoral training, the types of interdisciplinary practices enacted in these settings, and whether they can be fully integrated within universities. With regard to the expectations of students and their possible futures, longitudinal studies could be carried out to investigate the career
paths of students and to understand the extent to which interdisciplinarity affects careers. Further directions could be taken in analysing political strategies to achieve technological progress with research on interconnected issues of impact, research uses and transfer of knowledge between sectors.

Theoretically, this study has revealed that practice theory is valuable for interdisciplinary research. Instead of asking what interdisciplinarity is, practice theory asks how it is done and, thus, prevents researchers from assuming vague definitions or from ignoring the multiple meanings attached to the term. Future research should be specific in the way interdisciplinarity is conceptualised while acknowledging the difficulty in finding a universal definition.

The present study has highlighted the challenges posed by interdisciplinarity by equating it with a chimera and has shown how the policy sphere attempts to capitalise on academic knowledge clash with academic institutions and their traditional pursuit of scholarship. As discussed in chapter 8, the UK Government’s misunderstanding of interdisciplinarity as synonymous with collaboration across disciplines and sectors perpetuates the outdated linear model of innovation. While interdisciplinarity is imagined as a solution for improving the country’s economic position worldwide, it remains an ideological force and a political instrument for the governance of universities and science to serve the interests of capitalism and its markets. The political rhetoric continues to drive the idea that new researchers will enjoy autonomy and freedom in their research and will flourish in exciting careers. This
rhetoric hides the fact that interdisciplinarity is a powerful driver behind continuous attempts to make academia and science impactful for broader society, underpinning the needs for accountability, competition and other business-like demands.

Universities respond to these social and political forces by marketing interdisciplinarity and interdisciplinary doctoral programmes in order to compete with each other globally for prestige, rankings and funding. However, academic values and practices of research communities remain firmly anchored in disciplinary norms that drive the way interdisciplinarity is implemented in universities. Individual researchers or communities of researchers that are personally invested in interdisciplinary practices continue to collaborate with other disciplines and different stakeholders, as has long been the case. Other groups take advantage of available funding for interdisciplinarity to label their research as such, often falling short of producing truly integrated insights but struggling to overcome the challenges of collaborative work. Others still, like CDT-OPTIMA, as was found in this study, rest on a specific interpretation of interdisciplinarity that is closely aligned with the idea of growing a disciplinary field that draws on multiple disciplines.

Such doctoral programmes do not seek to integrate insights from different disciplines but to assemble methods and tools to answer known problems in science. Students are exposed to different ways of thinking and to large numbers of actors external to the university and, as such, are trained to be
collaborators rather than interdisciplinarians. However, the core disciplinary
dynamics of scholarship present challenges for this type of doctoral training.
The present study found that socialisation remained a crucial issue in
doctoral training and argued that this process is hindered by the lack of experts and role models in proximity to students. There also remains to be seen whether previous students’ networks could be sustained once the students graduate to strengthen ties and offer the opportunity for future work collaborations or to avoid the next cohorts of students having to “reinvent the wheel”. This particular issue was not investigated in the present study.

Overall, by investigating interdisciplinary practices in the context of the university, this study found that while new doctoral programmes are funded and set up, little evidence has been found about changes in the disciplinary organisation of institutions. Further research may add to the debate of whether universities are becoming more interdisciplinary and possible consequences for the scientific enterprise and broader society.
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**Appendix A – Group interview schedule**

Student Experience (Community / Identity / Voice / Belonging)

In CDT-OPTIMA (Interdisciplinary Setting)

Differing disciplines in supervisory team
- Where do you feel at home? Why?
- Do you belong in all research groups? Why?
- How does where you feel at home match your original discipline?
- What part does the supervisor play?
- How do you describe yourself (in terms of your discipline)?

OPTIMA Identity

- Does this exist?
- How does it manifest itself?
- What does an OPTIMA student look like?
- What do they want career-wise?

Being an “interdisciplinary” student

- Pros and cons?
- How do you see yourself compared to other (mono-disciplinary) students?

Community

- Describe the communities you belong to, e.g.:
  - OPTIMA
  - Lab groups
  - Other
  - How do they compare?

Notes for data Collection

Which cohort are you in?

How do students define themselves (status: researcher/students; discipline)

Where are students based primarily? (Edinburgh or Strathclyde)

Future career plans?
Appendix B – Interview schedule

Motivations for undertaking an interdisciplinary PhD with CDT-OPTIMA
Previous educational or professional experiences
PhD for entering academic workforce or other sectors/jobs
Interests in business and entrepreneurship, translational science, healthcare and/or technologies
Why choose CDT-OPTIMA specifically?
Do you enjoy working with researchers from different disciplines?

During the PhD
Where are you based? Different sites, labs, cities.
You arrive on your first day, how do you get started, what happens?
How do you start learning disciplines you are not familiar with?
What type of project are you working on?
What is it like to work across disciplines?

Relationships
Are there other CDT-OPTIMA students in your lab/office?
Supervisors: how many, their location, relationships, meetings, any issues
Who do you go to if you have any issues or questions?
Do you feel supported by CDT-OPTIMA? Resources, pastoral care.
Do you feel part of the CDT, the university, the lab, your cohort?

Future career
Do you expect an interdisciplinary PhD will help you in your future career?
What main skills do you think you are developing in your PhD will help you most in your career?
Is your project something you would like to continue exploring after your PhD?
Academia or other sectors?
Have you thought about possible future careers?

Work placements (if applicable)
What type of work placement did you undertake? How was it?
Was the work placement aligned with your studies, your area of interest, other?
What was the effect of the work placement on you?
What kind of experiences did the work placement offer? Skills, communication, jobs.
What skills acquired during your PhD do you think were the most useful on the placement?
Are work placements useful?
Reflections
What do you think is the strength of CDT-OPTIMA?
Did you encounter any difficulties, problems, issues? Any other thoughts?
Appendix C – Example of mapping used for data analysis
Appendix D – CDT-OPTIMA letter

The EPSRC and MRC Centre for Doctoral Training in Optical Medical Imaging

School of Chemistry,
Joseph Black Building,
David Brewster Road,
Edinburgh, EH9 3FJ.

23rd April 2019

Dear Sir/Madam,

Nathalie Dupin is a PhD student jointly funded by OPTIMA/School of Chemistry and the School of Social and Political Science.

Nathalie proposes to conduct her doctoral research on interdisciplinary research training. OPTIMA students and their programme will be one of her sources for data collection.

I am writing to you on behalf of OPTIMA to confirm that Nathalie Dupin is an independent researcher and as such is entirely free to conduct her original research (under the supervision of Prof Catherine Lyall).

OPTIMA is part-funding Nathalie in the area of research into interdisciplinary training which we hope will provide an evidence-base for future developments in this area, however OPTIMA management will not influence her research in any way. Nathalie Dupin will operate and carryout her PhD with full independence.

We look forward to working with Nathalie.

Yours sincerely,

Dr Jean O’Donoghue
OPTIMA Manager
CONSENT FORM

Title of Project: The Influence of interdisciplinary training on the next generation of researchers

Name of Researcher: Ms Nathalie Dupin

1. I confirm that I have read the information sheet dated 26th September 2018 for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I agree to take part in the project. Taking part in the project will involve participating in group discussions, interviews and/or observations. Data may be audio recorded and notes will be taken during the different interactions.

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, and without penalty.

4. I understand my personal details will not be revealed to any other people, including the project management team. Any identifiers will be removed from transcripts/notes and subsequent publications except for the names of the university and the CDT.

5. I understand my words may be quoted anonymously in research outputs.

Name of Participant  Date  Signature
Appendix F – Participant information sheet

Title of Project: Interdisciplinary doctoral training: becoming a researcher across disciplines

Name of Researcher: Ms Nathalie Dupin

You are invited to participate in the above research project.

The following information is provided to help you decide whether you wish to take part. Please ask me, Nathalie Dupin (Nathalie.Dupin@ed.ac.uk), if there is anything that is unclear or if you would like more information.

Purpose of the research

The aim of the project is to collect a rich understanding of how interdisciplinary research training is delivered and what it means to become an interdisciplinary researcher in the UK.

The research will include discussions, interviews and observations in laboratories and other institutional or social settings. The research will be based primarily on student perspectives and experiences, supplemented by views from academic and administrative staff. Therefore, as a key stakeholder, I would be grateful if you would be willing to take part in the research. Your participation is entirely voluntary. If you decide to take part, you will be asked to sign a consent form detailing how your data will be treated.

As a research participant, you may be invited to take part in discussions, interviews and observations on more than one occasion. You will be invited to attend separate events by email, at a mutually agreed time and location, and to confirm your consent. It is up to you whether you participate, when and how many times. You may withdraw your consent and participation by sending an email to Nathalie.Dupin@ed.ac.uk.

PARTICIPATION IS VOLUNTARY. YOU MAY WITHDRAW AT ANY TIME.

Whilst there are no immediate benefits for participating in the project, this work will contribute to a deeper understanding of interdisciplinary education in the UK and will enable participants to express their perspectives.

All information collected during the discussions, interviews and observations will remain strictly confidential and will be used by the researcher solely. Reports resulting from the research will be anonymised and any personal details or information that could lead to your identification will be removed thereby preserving confidentiality.
**Contact for further information**

Prof Catherine Lyall (Supervisor)
Email: C.Lyall@ed.ac.uk
The University of Edinburgh
School of Social and Political Science,
Science, Technology & Innovation Studies.

**Audio/photo recording**

For transcription purposes, discussions and interviews may be audio recorded and securely disposed of after completion. The recordings will not be used for any other purposes.

This research project is funded by the University of Edinburgh.

Thank you for taking the time to read this information sheet and for considering taking part in this research. I look forward to meeting you.