Creative Arts and STEM Fusion in and around the UK Creative Industries: A multi-level study

Martha Bloom

Thesis submitted for the degree of Doctor of Philosophy in Technology and Innovation Management

Science Policy Research Unit (SPRU), University of Sussex, Brighton, UK

October 2021

UNIVERSITY OF SUSSEX | BUSINESS SCHOOL | SCIENCE POLICY RESEARCH UNIT

Declaration

I hereby declare that this thesis has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.

The content of the thesis and all papers contained herein are entirely the candidate's own single authored original work.

Signature: Martha Bloom

Acknowledgements

Work on this thesis has been generously funded by the R&D Management Association (RADMA) under their Doctoral Studies Programme. Without their funding this thesis could not have been written and I am extremely grateful for their support.

I would like to begin by thanking my supervisors, Josh Siepel and Roberto Camerani for all the help, advice, and guidance they have offered me throughout the PhD. I could not have asked for a more supportive and enthusiastic supervisory team. Thanks also to Puay Tang who supervised the first year of this PhD. Though Puay is sadly no longer with us, right up to the last draft of the thesis I continue to think 'what would Puay say about this'. All three of my supervisors have shaped not only the work, but who I am as a researcher, and I will be forever grateful to them all. In that vein, a special thanks goes to Ed Steinmueller, who inspired and encouraged me to pursue a PhD and who supported my (many) funding applications. I cannot thank him enough for giving me the courage to start on this journey. A big thanks also to Tim Foxon for all his support as Director of Doctoral Studies, especially during a difficult first year, and to Marion Clarke for her help on the many, many administrative issues I have come to her with over the course of my time at SPRU. Additionally, I would like to express my great appreciation to my examiners Mariachiara Restuccia and Roberta Comunian for their considered and conscientious engagement with my thesis and for their insightful comments and advice.

I am also grateful for the comments and advice offered on early drafts of this work from members of my annual review panels, Kat Lovell, Daniele Rotolo, Ohid Yaqub and Michael Hopkins, and for the comments and advice offered by Bruce Tether, Patrizia Casadei and the editors of the SPRU Working Paper Series (SWPS) on the first paper presented in this thesis. Thanks also go to Hasan Bakhshi, Franz Buscha, Dinah Caine, Sir Nigel Carrington, Frances Corner, Geoffrey Crossick, Lesley Giles, Nick Johnstone, Gary Sprules, Edward Venning, Andrew Westwood and Jon Zeff for their advice on related work which lead to improvements in this thesis. I am also extremely grateful to Rebecca Vine for her invaluable advice on study design and early drafts of the second paper presented in this thesis. A huge thanks also to Matt Fox for so generously organising my fieldwork at Framestore (as well as for the numerous hours of talking through my ideas!), and to all those who participated in interviews.

They say that if you want to go fast, go alone but if you want to go far, go together. My PhD journey has certainly not been fast, but looking back on how far I have come from my first days as a PhD student, I am certain I would not have made it this far without the help of my friends and colleagues at SPRU. Throughout the PhD, the SPRU community has been like a second family and I could never have hoped to find such a welcoming, generous and kind group of people. For all the lunch time chats, tea breaks, Friday cakes and after work drinks, for all the advice on theory, methods, and writing, for all the memes, puns and silliness, for every celebration of a birthday, holiday or viva, for every act of kindness, small and large, my heartfelt thanks goes to Anna Watson, Alex Ghionis, Bryony Parrish, Kejia Yang, Pavel Corilloclla Terbullino, KJ Han, Claudia Obando Rodriguez, Ben Dempsey, Charlie Dobson, Melina Galdos Frisancho, Donal Brown, Duncan Edmondson, Vedad Sabljic, Bernardo Caldarola, Bernardo Cantone, Josh Moon, Filippo Bontadini, Bipashyee Ghosh, Vasilis Gkogkidis, Pippa Groome, Sofia Kesidou and Janna Alvedalen.

Finally, I would like to thank all my friends and family outside of SPRU. A special thanks goes to my mother, father, brother, aunt and in-laws who have provided the foundations for me to conduct this work; to Serena, who has been a constant source of energy, motivation and intelligent advice; and to Sam, without whom I would not have started this journey. Like most PhDs, there have been many ups and downs over the last few years. I am forever grateful to my partner, who has been by and on my side through them all. They have helped in the creation of this thesis in more ways than I could possibly count.

Thesis summary

The most innovative firms in the creative industries have been shown to be those which draw on, or 'fuse', creative arts and STEM (Science, Technology, Engineering and Mathematics) skills. However, little is known about how this fusion operates in practice. The thesis addresses this gap by investigating how the fusion of creative arts and STEM skills at the individual, firm and inter-firm level contribute to innovation in and around the UK creative industries. At the individual level, the thesis examines the relationship between STEAM (STEM+Arts) education and graduate employment outcomes in the creative industries using official data from the UK Higher Education Statistics Agency. At the firm level, the thesis explores how the interplay of different forms of common and diverse knowledge shapes the way in which new knowledge is formed, through a qualitative case study of a major London based visual effects company. At the inter-firm level, the thesis examines the fusion of creative arts and STEM skills in the context of publicly funded R&D collaborations, using a dataset of all InnovateUK funded projects between 2004-2020. Overall, this interdisciplinary and mixed methods thesis makes a significant original contribution to knowledge by firstly defining and subsequently expanding upon a definition of fusion as a multi-level construct. By bringing together theories of fusion from differing disciplines to examine fusion at each key level of analysis, the thesis contributes a more extensive investigation of the notion of fusion than has previously been achieved. In doing so, the thesis offers significant contribution to innovation studies literatures and theoretical debates around diverse/common knowledge, developing a novel theoretical framework which helps to explicate the interplay of different forms of knowledge in innovation processes. Moreover, the thesis contributes empirical findings on the value of STEAM education and the extent to which UK innovation policy is supporting fused collaboration projects, both of which have significant implications for policy making.

Contents

List of tables

List of figures

List of abbreviations

AFTA	America for the Arts
BAFTA	British Academy of Film and Television Arts
BTEC	Business and Technology Education Council
CA	Creative Arts
CFX	Creature Effects
CG	Computer Graphics
CI	Creative Industries
CKB	Combinatorial Knowledge Bases
CRN	Company Reference Number
DCMS	Department for Culture Media and Sport
DLHE	Destination of Leavers from Higher Education
DLHE Long	Destination of Leavers from Higher Education Longitudinal Survey
DOT	US Dictionary of Occupational Titles
FE	Further Education
FX	Effects
GLC	Greater London Council
GVA	Gross Value Added
HE	Higher Education
HEFCE	Higher Education Funding Council for England
HESA	Higher Education Statistics Agency
JACS	Joint Academic Coding System
KI	Knowledge Integration
LH	Learning Hours
NHS	National Health Service
NVQ	National Vocational Qualification
O*NET	Occupational Information Network
OECD	Organisation for Economic Co-operation and Development
PSO	Public Sector Organisation
PSRE	Public Sector Research Establishment
R&D	Research and Development
SIC	Standard Industrial Classification
SOC	Standard Occupational Classification
STEAM	Science, Technology, Engineering, Arts and Mathematics
STEM	Science, Technology, Engineering and Mathematics
UCAS	Universities and Colleges Admissions Service
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
VFX	Visual Effects
WIPO	World Intellectual Property Organization

"It is hardly possible to overrate the value [...] of placing human beings in contact with persons dissimilar to themselves, and with modes of thought and action unlike those with which they are familiar"

John Stewart Mill, 1848[1]

[1] (Mill, 2000 [1848], p.677)

1. Introduction

1.1. Introduction and thesis structure

Since the late 1990s, policy makers across the globe have heralded science, technology and engineering sectors as a panacea of economic development and growth (Blackley & Howell, 2015). In the UK, innovation policy has explicitly targeted such sectors and has widely promoted STEM (science, technology, engineering and mathematics) skills, presumed to be the preserve of these sectors, since the early 2000s (e.g.: Sainsbury, 2007)[2]. Despite increased policy interest in the creative industries in recent years (e.g.: HM Government, 2017, 2018), the persistent focus on STEM has led to innovation policy which explicitly excludes non-scientific innovation from definitions of research and development (see Bird et al., 2020) and education policy which valorises STEM provision at the expense of creative arts subjects (e.g.: Augar, 2019; DfE, 2021).

Yet there is growing recognition of the contribution that the creative industries are making to economies worldwide (Lhermitte et al., 2015; UNESCO, 2018), and strong evidence to suggest that creative sectors are driving economic growth in the UK. Roughly 1 in every 16 jobs in the UK are in the creative industries and the sector contributes £111.7bn to the economy, accounting for 5.8% of total UK GVA (DCMS, 2019b, 2020). In addition, their economic contribution is growing, with creative industries GVA increasing by 43% from 2010 to 2018, compared to an increase of around 17% for the UK economy as a whole, and employment rising by 31% in the same period, over three times the overall growth rate of UK employment (DCMS, 2019b, 2020). Moreover, evidence suggests that the creative industries are one of the most innovative sectors of the economy (Bakhshi & McVittie, 2009; Müller et al., 2009), as well as being a driver of innovation in other sectors (Bakhshi & McVittie, 2009; Potts, 2009). In light of the growing importance of the creative industries, research has aimed to map the sector's impact (Chapain et al., 2010; Lhermitte et al., 2015; Mateos-Garcia & Bakhshi, 2016), identify barriers to its growth (Nesta, 2006; Comunian, 2009), and discern the skills needed to support it (Creative Skillset, 2014; Creative Industries Federation, 2016).

This burgeoning body of work indicates that the creative industries are a vital engine of growth for the UK economy and that these creative sectors require not only STEM skills, but advanced creative arts skills as well (Docherty, 2010; Livingstone & Hope, 2011; Bakhshi et al., 2013; Dass et al., 2015; Neelands et al., 2015; Bazalgette, 2017; Sleeman

[2] Arguably, UK innovation policy has always focused on science and technology sectors, however this appears to be the first period in which the STEM acronym began to be used and is one in which the issue has achieved significant traction.

& Windsor, 2017). Further, it has been shown that combining creative arts and STEM skills in creative industries firms leads to greater innovation and firm growth (Sapsed et al., 2013; Siepel et al., 2016, 2019). However, there is a tendency to "[perceive] of creatives and technologists as distinctive actors", encompassing fundamentally different languages, understandings and attitudes (Mangematin et al., 2014, p.6). It has also been suggested that "how diverse experts come together, overcome differences in understanding and interests, and create value remains areas in need of both theoretical and practical advances" (Edmondson & Harvey, 2018, p.11). The thesis addresses this gap by investigating how creative arts and STEM skills are integrated in the creative industries, referred to here as 'fusion'. The thesis takes a multilevel and mixed methods approach to fusion, investigating the concept at the individual, firm and inter-firm levels.

In its first paper, the thesis investigates the concept of fusion at the individual level, by comparing graduate outcomes for those who studied a mix of creative arts and STEM subjects with those who have a solely creative arts or STEM educational background, using a dataset of all graduates in the year 2012/13 from the Higher Education Statistics Agency (HESA). In its second paper, the thesis examines the concept of fusion at the firm level by qualitatively investigating the interplay of diverse and common knowledge in processes of knowledge integration, through a case study of a highly innovative firm in the visual effects industry. In its third paper, the thesis investigates fusion at the inter-firm level by assessing R&D collaborations between creative and STEM based firms, using a dataset of all collaborative R&D grant awards made by the UK government via its innovation agency InnovateUK between 2004 and 2020. Finally, in the discussion chapter, the thesis introduces the idea of knowledge liminality as a way of conceptualising how fusion operates at each of the levels of analysis. Overall, the thesis contributes empirical findings on the importance of fused education to the UK creative industries and the extent to which UK innovation policy is supporting fused R&D collaborations, both of which have significant implications for policy making. The thesis also offers a significant contribution to theoretical debates around diverse/common knowledge, presenting a novel theoretical framework which helps to explicate the interplay of different forms of knowledge in knowledge integration processes, which has significant implications for both theory and management practice. Moreover, by first defining and then expanding upon a conceptualisation of fusion as a multi-level construct, the thesis extends extant research on the topic and offers a theoretical basis from which future research in this area can benefit.

Table 1 below details each paper in the thesis, its main research question, methodological approach and main area of contribution.

Table 1 – Papers outline

	Paper 1	Paper 2	Paper 3
Title	Mono-specialists and trans-specialists in the Creative Industries: Mapping Creative Arts and STEM Skills Fusion in the UK Graduate Workforce	Reassessing the Role of Common Knowledge in Processes of Knowledge Integration in the Visual Effects Industry	Working with the Creative Industries: Knowledge Base Combinations in Publicly Funded Collaborative R&D Projects
Research Question	What is the relationship between STEAM education and graduate employment outcomes in the UK creative industries?	How does the interplay of different forms of common and diverse knowledge shape processes of knowledge integration in the UK creative industries?	To what extent is innovation policy in the UK supporting creative industries firms in engaging in formal R&D collaborations with firms from STEM sectors and how do such collaborations differ to projects which involve less sectoral variety?
Level of Analysis	Individual	Firm	Inter-firm (Collaborative R&D Projects)
Data	Official dataset of all UK graduates in the year 2012/13 (n=~700,000) and employment outcomes 6 months after graduation (n=~427,000) and 3 years after graduation (n=~107,000)	Seven data types including interviews, survey data, documentation and observations from a large visual effects company based in the UK	Official dataset of all InnovateUK funded collaborative R&D projects between 2004-2020 (n=5,241) matched with organisation level data from FAME and Companies House (n=7,045)
Data Source	HESA	Original Data	InnovateUK, FAME, Companies House
Methodological approach	Quantitative. Descriptive and econometric data analysis.	Qualitative. In depth case study.	Quantitative. Descriptive and econometric data analysis.
Theoretical approach	Multidisciplinary/ interdisciplinary education	Knowledge integration	Combinatorial knowledge bases
Area of main contribution	Empirical	Theoretical	Empirical

This chapter begins by offering some contextualisation of the papers, through examination of the centrality of both creative arts and STEM knowledge to the creative industries. It then presents the main research questions before explicating the theoretical and methodological approaches taken in each paper, and how these fit together. Chapters 2, 3, and 4 present each of the three papers. Chapter 5 offers discussion of how the findings of each paper can be brought together to offer insight into the relationship between fusion as a multi-level construct and the creative industries. This final chapter concludes with policy recommendations and suggested areas of future study.

1.2. Empirical context

1.2.1. Introducing fusion

The idea that the arts and sciences significantly influence one another is not a new idea. In ancient Greece, there was little distinction between artistic and scientific enquiry, with many key thinkers investigating aesthetics, music, mathematics and natural science concurrently (Bullot et al., 2017). During the 15th century, De Vinci exemplified 'the renaissance man', highly skilled in both art and science, and combining the two approaches to make seminal artistic and scientific discoveries. The enlightenment period was characterised both by great leaps in scientific discovery and in the way the arts were utilised to explore and present scientific evidence, where "art and science became allies to illuminate the mind in a union of logic and imagination" (Blatchford & Blyth, 2019, p.14).

Yet in the mid-19th century, European education systems began to segregate the arts and sciences, valorising the 'scientific method' of objectivity and relegating the humanities' tenets of critique and interpretation (Blair & Grafton, 1992). This compartmentalisation echoed wider shifts towards knowledge specialisation in both academia (Bracken (Née Bull) & Oughton, 2006) and industry (Pavitt, 1998; Brusoni et al., 2001), where increasingly specialised industrial activity required increasingly specialised technical knowledge. In 1959, C.P. Snow gave the now infamous 'two cultures' lecture, later turned into a widely read and hugely influential book. In it, Snow speaks of the "gulf of mutual incomprehension" between artists and scientists, founded and facilitated by an education system which siloes disciplines behind high walls and forces students to choose between them (Snow, 2012 [1959], p.4). It is easy to see how the disciplinary siloes forged through education can lead to chasms in understanding between professionals who have gained not only their expertise, but to a certain extent their identities, through the training and socialisation they are exposed to through the education system.

Work has been done to try to overturn the 20th century's siloed separation of the arts and sciences. During the 1960's, a wave of 'art-and-technology' initiatives emerged in multiple countries (McCray, 2020), including the prominent Experiments in Art and Technology (E.A.T.) project which aimed to bring together artists, technologists and engineers with great success (La Prade, 2002; Martin, 2015). Since then there have been many further projects aiming to integrate creative arts and STEM in gallery, laboratory and education settings (see Beck & Bishop, 2018). In education literature too, much has been discussed about the benefits of combining arts and science based disciplines. The term 'fusion' was first used to describe the synergistic integration of creative art and STEM in the title of an article in the Journal of Art Education in 1985. Here the authors argue that advances in, and the proliferation of technology necessities a closer relationship between the arts and sciences, adding that "the rich media mix that comes from this synthesis will add to both our technology and our humanness" (Adams & Fuchs, 1985, p.22). Similar arguments are made today, within the STEAM (STEM +Arts) movement, arguing for better integration of the arts and sciences in the school curricula (see Bequette & Bequette, 2012; Wynn & Harris, 2012; Land, 2013; McAuliffe, 2016; Colucci-Gray et al., 2019).

However, despite longstanding calls for better integration of creative arts and STEM subjects in education, it could be argued that the 'gulf' of which Snow spoke in the late 1950's has not subsided, but has instead expanded, as "the division between art and science happens at an increasingly young age, deepening and widening by the time university education is reached" (Wallace & Barber, 2013, p.18). Here we see how the UK education system funnels students into distinct arts or sciences pathways, where students "focusing on the former may not develop technical skills, while those selecting the latter path may not be given the chance to develop their creativity" (Dass et al., 2015, p.48). Bilton and Leary observe the effect this can have on the creative industries: "reinforced by an education system which channels creative and non-creative subjects into separate streams from an early age [...creative and non-creative workers] see the world and each other from opposite perspectives" (2002, p.61).

Such assertions reflect how the UK education system and increased industry specialisation have conspired to generate dichotomies of creative and scientific persons; of 'lovies' and 'boffins' (Schmidt, 2011) or 'hipsters' and 'geeks' (Rodríguez-Pose & Lee, 2020). Yet, as this thesis will argue, it is not the delineation but the coming together, or fusion, of creative arts and STEM skills that has fuelled the creative industries' growing importance and success.

1.2.2. Fusion and the creative industries in the UK

In order to more fully understand why the concept of fusion is so central to the creative industries today, it is important to understand how the creative industries have evolved. During much of the 20th century, UK cultural policy was largely divided along 'market' and 'cultural' value lines, which was "marked by a division of policy responsibility between the Department of Trade and Industry for the press, the Postmaster General and later the Home Office for broadcasting, and the Arts Minister and the arms-length Arts Council for the arts" (Garnham, 2005, p.16). Here the arts were treated primarily as a social good, rather than an active component of the economy. The term 'cultural industries' was first used in a UK policy context in 1979 by the Greater London Council (GLC), whose 'cultural industries strategy' aimed to harness the wealth creation of many areas of cultural production at a local level that currently fell outside of the government funding system (O'Connor, 2000). The GLC used economic tools of value chain analysis and employment mapping, taking an industry focused approach to policy making that sought to achieve both cultural and economic objectives. However, in 1986 the GLC was abolished and cultural policy at a national level continued in much the same vein as it had throughout the 70's and 80's.

The election of Labour in 1997 brought about the first real interest in the cultural industries at a national level. The Department for Heritage became the Department for Culture Media and Sport (DCMS), in an attempt to "take us away from the notion that this is simply the 'ministry of fun' to an understanding of the scale of the serious economic value of the work sponsored by the department" (Smith, 1998, p.2). This rebranding of the department also encompassed a rebranding of the 'cultural industries' to the creative industries, and with it the creation of the Creative Industries Taskforce to first identify and then promote policy directed towards the UK creative industries (Flew, 2011).

The DCMS published its first Creative Industries Mapping Document in 1998, encapsulating the new found vigour for an economic analysis of cultural work and "firmly establish[ing] the cultural industries as a legitimate object of policy" (O'Connor, 2007, p.49). This shift in name also reflected the wider scope of the DCMS's new creative industries, which now included many sectors (such as software development and marketing) that previously lay outside the remit of the old Department for Heritage. The definition of the creative industries used by the DCMS has been adopted by policy makers worldwide (Ross, 2007) and arguably marked a key turning point in the development of cultural policy both in the UK and internationally (BOP Consulting, 2010; Gross, 2020).

This move not only emphasised the economic potential of what had previously been thought of as 'The Arts', but firmly reinstated the link between art and technology by actively encompassing both traditional arts sectors and the booming technology sector in one definition. The DCMS defines the creative industries as: "those industries which have their origin in individual creativity, skill and talent and which have a potential for wealth and job creation through the generation and exploitation of intellectual property" (DCMS, 2001). As this definition centres around individual creativity, the operationalisation of such a conception is based upon industry sectors with a high concentration of 'creative workers'. The definition of a creative worker is based on a list produced by the DCMS of 'creative occupations', and the DCMS used data from the national Annual Population Survey to determine how many of these creative workers were employed in each industry. The DCMS refer to this as 'creative intensity'. Any industry in which over 30% of the workforce is employed in a creative occupation – 30% 'creative intensity' – is considered to be in the creative industries. This methodology provides the DCMS with a list of 31 industry subsectors (see appendix 1 for full list) which make up the creative industries. These sectors are clustered into the following nine subsector groups: 'Advertising and marketing', 'Architecture', 'Crafts', 'Product, graphic and fashion design', 'Film, TV, video, radio and photography', 'IT, software and computer services', 'Publishing', 'Music, performing and visual arts', and 'Museums, galleries and libraries'[3] (DCMS, 2016).

The DCMS definition of the creative industries is not without criticism (Garnham, 2005; O'Connor, 2009; Flew, 2013; Spilsbury & Godward, 2013; Campbell et al., 2019) and many competing conceptualisations and operationalisations have been put forward. Notable alternative conceptual models include the Concentric Circles Model proposed by Throsby (2001, 2008b), which was later developed by KEA European Affairs (2006) in Europe and The Work Foundation (2007) in the UK, in which the 'core creative arts' are the primary producer of creative ideas, and these ideas diffuse throughout the economy through the presentation and production of cultural goods and services (Throsby, 2008b). There is also Nesta's ecosystem approach (Nesta, 2006) which conceives of the

[3] Note that 'Library and Archive Activities' and 'Museum Activities' have 23.8% and 22.5% creative intensity respectively, which is under the 30% threshold for the creative industries. They have, however, still been included in the definition by the DCMS after consultation.

creative industries as a complex interplay between service providers, content producers, experience providers and originals producers. Notable alternative definitions (based upon a variety of conceptual models) include the WIPO definition of copyright industries (WIPO, 2003, 2015), the UNESCO definition (UNESCO, 2009, 2012) and the OECD definition (OECD, 2014). Each definition relies on slightly different conceptualisations of what constitutes a creative industry, and different methodologies for operationalising such conceptualisations (see UNESCO Institute for Statistics, 2012 for full methodological and international comparison). As such, each definition includes slightly different industry sectors (see Table 2 below). However, what is clear from all definitions of the creative industries is their reliance not only on creative talent, but also on the use of technology.

Table 2 – Comparison of creative industries definitions based on DCMS categories

Sector	DCMS (2016)	WIPO (2015)	OECD (2014)	UNESCO (2009)	UNCTAD (2010)	KEA (2006)	AFTA (2004)
Advertising and Marketing	X	X	X	X	X	X	-
Architecture	X	-	X	X	X	X	X
Craft	X	-	-	X	X	X	X
Design: product, graphic and fashion design	X	X	X	X	X	X	X
Film, TV, video, radio and photography	X	X	X	X	X	X	X
IT, software and computer services	X	X	X	X[4]	X	X[5]	-
Publishing	X	X	-	X	X	X	X
Museums, galleries and libraries	X	X	-	X	X	X	X
Music, performing and visual arts	X	X	X	X	X	X	X
Copyright collective management societies	-	X	-	-	-	-	-
Gastronomy	-	-	X	-	-	-	-
Cultural and natural heritage	-	-	-	X	X	X	-
Manufacture of content accessing devices (e.g. PCs, Mp3 players, etc)	-	-	-	-	-	X	-
Arts schools and services	-	-	-	-	-	-	X

Sources: (America for the Arts, 2004; KEA European Affairs, 2006; UNESCO, 2009; UNCTAD, 2010; OECD, 2014; WIPO, 2015; DCMS, 2016)

This explication of the history of the creative industries as a distinct industry categorisation, and the overview of differing conceptualisations and operationalisations of this categorisation, serves to demonstrate why the fusion of creative arts and STEM skills is of such fundamental importance to this sector. Whilst science, technology, engineering and mathematics have always played a role in artistic endeavours, and creativity could be said to be at the heart of all scientific enquiry, the codification of the creative industries as a sector encompassing both technological and artistic outputs

[4] Videogames and online streaming of creative content only
[5] Videogames only

solidifies the interdependence of these two fields in driving innovation and economic growth.

1.2.3. Motivation and literature gap

Having introduced the concept of fusion and its relevance to the creative industries, it is worth spending some time explicating how the notion of fusion in the creative industries has been linked to innovation in extant literature. Perhaps the first piece of work to examine the link between the fusion of creative arts and STEM skills and innovation specifically in creative industries firms was the Brighton Fuse report (Sapsed et al., 2013), which conducted a large scale survey of creative industries firms in Brighton, UK. The report found that firms who report that they fuse creative arts and STEM skills in their work grew faster and were more innovative than firms that did not. Further, it was found that the more fused firms were, the more likely they were to develop new products and services. This report was followed by work which established that the fusion of creative arts and STEM skills at the firm level increased the growth prospects and innovation capabilities of firms across the UK (Siepel et al., 2016) and work which evidenced that "the benefits of both STEM and creative skills arise only when these skills are combined" (Siepel et al., 2019, p.0).

This small but important body of work points to the innovative benefits of combining creative arts and STEM skills within creative industries firms. However, while these papers find a strong link between fusion and innovation at the firm level, they do not explore how this fusion takes place, or establish the processes occurring at the firm level to enhance creative industries firms' innovation capabilities. It is well established that drawing on a diverse range of knowledge from different domains can promote innovation by increasing opportunity for novel combinations of ideas to emerge (Schumpeter, 1934; Cohen & Levinthal, 1990; Kogut & Zander, 1992; Tiwana & Mclean, 2005). Yet, integrating knowledge across disciplinary boundaries can be challenging and requires strong firm level processes and routines to manage successfully (Szulanski, 2002; West, 2002; Tell et al., 2017). In the context of creative work, these challenges are further increased by the need to balance tensions between creative and economic priorities (Caves, 2000) and to create innovation processes which allow for the ambiguity and dynamism necessary to produce goods and services whose value cannot always be objectively assessed (Lampel et al., 2000). Accordingly, the findings of studies such as the Brighton Fuse report require substantial further investigation in order to understand the firm level processes that underpin the ability of creative industries firms to translate the fusion of creative arts and STEM skills into innovation.

Furthermore, it remains unclear in extant studies of fusion at the firm level, the extent to which this fusion of skills is being driven by the combination of discrete creative arts and STEM specialists, or the employment of workers who have both skillsets. The presence of both creative and STEM skilled labour at the firm level has been shown to promote innovation in a German (Brunow et al., 2018) and Swedish context (Grillitsch et al., 2019). This might suggest that it is the presence of both creative and STEM specialists within an organisation which contributes to innovation. However, interdisciplinary working between diverse experts can be challenging without the presence of 'boundary spanners' – teams or individuals who sit at the intersection of different knowledge domains and are able to bridge the gap between disciplinary or functional groups (Marrone, 2010). In this vein, individuals who have training in both creative arts and STEM specialisms may contribute to the innovative capabilities of creative industries firms by bridging the cognitive, linguistic and social gap between creative arts and STEM domains. Indeed, recent research indicates that a combination of creative arts and STEM skills are required for roles in all creative industries sectors (Sleeman & Windsor, 2017) and that so called 'createch' skills, or skills which sit at the intersection of arts and technology are particularly associated with creative occupations that are predicted to grow (Bakhshi et al., 2019). These findings suggest that both skills specialists and individual workers who themselves have a fused skillset might be contributing to the innovative capabilities associated with skills fusion at the firm level. However, while these papers present strong evidence for the need for both specialists and fused workers to support innovation in the creative industries (demand side), little is currently known about how common skills fusion is in the creative workforce or how these fused skills are developed (supply side).

Moreover, the benefits ascribed to skills fusion at the firm level, could potentially be achieved through strategic collaboration with firms holding different skills. Collaboration projects have been shown to increase a firm's innovation capabilities, through extending the firm's knowledge, networks and collaboration skills, and minimising the risk of research and development activities by sharing the costs associated with innovation (Martínez-Noya & Narula, 2018). Moreover, by collaborating across industry sectors, firms do not just gain access to additional resources and capabilities, but are able to draw on different approaches to leaning, problem solving and knowledge creation (Grillitsch et al., 2019). As such, inter-firm collaborations between different industry sectors can improve the innovation capabilities of all firms involved and can lead to more innovative outputs than collaborations between firms who share a knowledge base (Tödtling & Grillitsch, 2015). This suggests that beyond individual and firm level fusion, creative industries firms could be benefiting from the fusion of creative arts and STEM skills through strategic collaborations with firms from other sectors. However, little is currently known about the extent to which creative industries firms engage in formal R&D collaborations with firms from STEM sectors.

In summary, extant work has demonstrated a clear link between the fusion of creative arts and STEM skills in the creative industries and innovation at the firm level. However there remain significant gaps in our understanding of the processes involved in innovation within fused firms and a significant gap in our knowledge of the extent to which skills fusion and innovation at the firm level might be being supported by skills fusion at the individual and inter-firm levels. This thesis addresses these gap by exploring how the fusion of creative arts and STEM skills contributes to innovation in the UK creative industries. As aforementioned, the creative industries are one of the fastest growing sectors of the UK economy and much recent policy work has been directed to support the sector. By gaining a better understanding of how the fusion of creative arts and STEM skills can lead to innovation in the creative industries, policy makers can be better informed when targeting resources and programmes of work, and creative industries practitioners can learn how to improve their innovation capabilities.

1.3. Research questions and analytic framework

As discussed in the preceding section, the fusion of creative arts and STEM skills at the firm level has been shown to promote innovation. However, there remain gaps in our understanding of how this process occurs in practice and the extent to which firm level fusion might be being supported by fusion at the individual and inter-firm levels.

Accordingly, this thesis addresses as its main research question: *How does the fusion of creative arts and STEM skills contribute to innovation in the UK creative industries?*

In doing so, it addresses three sub-questions:

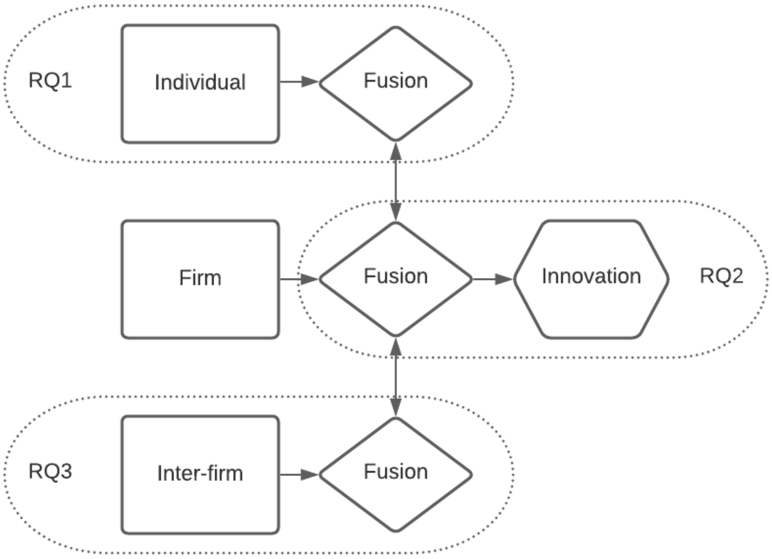
RQ1: *What is the relationship between STEAM education and graduate employment outcomes in the UK creative industries?*

RQ2*: How does the interplay of different forms of common and diverse knowledge shape processes of knowledge integration in the UK creative industries?*

RQ3: *To what extent is innovation policy in the UK supporting creative industries firms in engaging in formal R&D collaborations with firms from STEM sectors and how do such collaborations differ to projects which involve less sectoral variety?*

Figure 1 represents the analytical framework of the thesis and how the sub-questions fit together to address the main research question.

Figure 1 – Analytic framework



1.4. Conceptual, theoretical and methodological approaches

1.4.1. Conceptualising fusion

Before discussing the theoretical lenses that the thesis will apply to the concept of fusion, it is worth unpacking what is meant when discussing the fusion of creative arts and STEM skills. What is being fused – is it knowledge, skill, perspective? What makes creative arts and STEM different? Are they different at all? This section will begin by offering a brief explication of extant understandings of what constitutes skill, arguing that skills and knowledge are two terms so deeply intertwined that a clear distinction between the two is not only problematic, but not necessarily helpful in our investigation of fusion. In doing so, the section will outline the thesis' definition of skill as encompassing both knowledge and knowing, or information (both tacit and explicit) and proficiencies (ability to use knowledge), as embedded (within an individual, group or organisation) and embodied through action. Through this discussion it will be made clear that skill arises from education and training (either formal or informal) and as such, when looking to distinguish between the arts and the sciences, it becomes productive to consider what separates the two fields as different academic disciplines. Here it will be argued that the distinction between disciplines relies primarily upon differing 'knowledge structures', with differing approaches to knowledge creation. In doing so, the thesis will offer its definition of fusion as the combination of information and proficiencies (skills) arising from different methods of advancing knowledge (arts and sciences), that are embedded within an individual, group or organisation and embodied through action. Finally, this section will make the case for why fusion should be considered a multi-level concept, which can be applied at the level of the individual, the level of the group, organisation or firm, and/or at the level of inter-firm working.

Skills have been conceptualised in many different ways, depending on discipline (Green, 2011), theoretical position (Spenner, 1990) and epistemological outlook (Attewell, 1990). In relation to the role of skills in innovation, an appropriate place to start is considering the concept of skills from an economics perspective. A dominant theory in neoclassical economics, and highly influential wider afield, is human capital theory. With roots in the work of Mincer (1958), Johnson (1960) and Schultz (1961), human capital theory is perhaps best known by the work of Becker (2009 [1964]) who argued that in addition to physical capital (machinery, buildings, etc.) and financial capital, the skills and knowledge embedded in individual employees constitute a resource that provides significant value to the firm and should therefore be considered human capital. As such, human capital can be conceptualised both as the aspect of an individual's employment that creates value for firms in the workplace, and as an investment by the individual in acquiring abilities that directly relate to future earnings (Attewell, 1990). As Johnson explains:

> "In an advancing industrial society, both the provision of force and the elementary decision- taking are increasingly taken over by machinery, while what the worker brings to [their] task are the knowledge and skill required to use machinery effectively. [Their] knowledge and skill in turn are the product of a capital investment in [their] education in the general capacities of communication and calculation required for participation in the productive process, and the specific capacities required for the individual job" (Johnson, 1960, p.562)

Mincer states that "by and large, skill is an end-product of training", in which he includes both education and work experience (Mincer, 1958, p.292). As skills in this context are so closely aligned with education, training and knowledge, levels of skill are generally operationalised as level of education and years of work experience. Distinction between types of skill tend to fall in line with educational disciplines and industry sectors. As such, whilst the conceptualisation of skill in human capital theory is related both to the abilities an individual brings to a firm, and the requirements of the job role, in the operationalisation of skill, the latter is largely ignored. This focus on education, as opposed to task performance, has significant implications for the skill status of certain job roles. Where a job role has little or no association to a discrete educational discipline, the role is deemed to be 'low skilled' or 'unskilled', regardless of the tasks involved[6], while roles that are strictly connected to specific academic disciplines are venerated with the status of 'professional'.

Whilst the human capital conceptualisation of skill holds benefit in its ease of operationalisation, its methodological basis in positivism and rational choice, are problematic for many sociologists, who consider the distinction between 'skilled' and 'unskilled' work as socially determined. Such work sees the valorisation of particular skills, and the erasure or denigration of others, as a consequence of attempts to maintain social hierarchies, rather than accurate descriptions of the level of skill involved. For example, England's (1992) work on 'comparable worth' finds that job roles which require 'comparable' or similar levels of skill, are remunerated at different levels according to gender, race, and class bias. For many sociologists, a more accurate depiction of skill can be acquired through consideration of task demands; which skills are required for a role, rather than which skills an individual brings to a role (Green, 2011). Here level of skill is determined by the level of complexity of tasks, with greater skill indicated by the regularity and extent of the complexity of a role's duties (Attewell, 1990). This idea of task complexity has been taken up by organizational and management researchers, with many competing approaches to its measurement (Wood, 1986; Campbell, 1988).

Perhaps the most influential methodology for the measurement of skill as an aspect of job task are so called 'expert systems' which systematically categorise all skills required to perform an increasingly large number of job roles. The most widely used expert system is the Occupational Information Network (O*NET), which has been hugely influential in sociology (Spenner, 1990), labour economics (Frey & Osborne, 2017) and Human Resource Management (Converse et al., 2004), and forms the basis of the European Commission's classification of skills and competencies (ESCO, 2020). The O*NET builds on the work of the now defunct US Dictionary of Occupational Titles (DOT), developed in the 1930's as a tool to match skills demand with skills supply by systematically

[6] For example, Kusterer's (1978) interview with an 'unskilled' worker in which the worker begins "'I don't know why you want to interview me. You don't have to know anything to do my job.' Three hours later, too exhausted to keep writing down all she knew, I brought the interview to a close." (Cited in Attewell, 1990, p. 431)

recording all the skills necessary to carry out over 12,000 jobs (Peterson, 1992). The DOT was replaced by O*NET in the late 1990s, as an online database, with a slightly altered methodology from the original DOT. O*NET defines skills as "proficiencies or competencies that are developed through training or experience" (Reeder & Tsacoumis, 2017, p.1) and provides a taxonomy of 'basic' and 'cross-functional' skills.

The O*NET however, makes a distinction between skills and knowledge, with knowledge being defined as "The possession of a body of information (both factual and procedural) that is related to the performance of a task." (Peterson et al., 2001, p.463). Taken alongside the O*NET's definition of skill, we could therefore say that skill can be thought of as the ability to use knowledge to affect a desired end. Thus it is important to note that 'knowledge' in the form of information, is not the same as 'knowing' which is the utilisation of information in action. As Cook and Brown put it "we must see knowledge as a tool at the service of knowing not as something that, once possessed, is all that is needed to enable action or practice" (Cook & Brown, 1999, p.338). Conversely, knowing must also necessarily rely on knowledge. Consequently, both knowledge – either declarative or tacit (Polanyi, 2009) – and knowing are essential components of skill. Moreover, knowledge is not only utilised by individuals but is "embedded in the organizing principles by which people cooperate within organizations." (Kogut & Zander, 1992, p.385). Here we see how organisational routines and 'ways of doing things' capture collective knowledge beyond that held by individuals (Teece, 1982; Dosi et al., 2001; Winter, 2003), and embed "individually-held-knowledge-applied-in-the-firm" (Becker, 2004, p.660).

Consequently, this thesis uses the term 'skill' to encompass *both knowledge and knowing, or information (both tacit and explicit) and proficiencies (ability to use knowledge), as embedded (within an individual, group or organisation) and embodied through action.*

So far, we have established a working definition of skill as encompassing embedded and embodied knowledge and proficiencies. Moreover, the brief review of literature pertaining to skills has demonstrated that both skills and knowledge are gained through education, training and work experience (Peterson et al., 2001). Education and training impart both information (either tacit or declarative) and proficiencies (practiced abilities to use and manipulate knowledge in action). As such, in our investigation of fusion, it is useful to consider the fusion of creative arts and STEM skills as a fusion of disciplinary knowledge.

So what makes one academic discipline different to another? A longstanding approach to categorising differences between disciplines was developed by Biglan (1973a, 1973b), who argues that disciplines can be differentiated along three dimensions: hard vs soft, pure vs applied and life vs non-life. The hard or soft dimension relates to the extent to which a discipline holds singular paradigmatic values (hard) or there is a lack of consensus in knowledge or methods (soft). Pure and applied refer to the extent to which a discipline focuses on creating knowledge or applies extant knowledge to novel settings. The life dimension distinguishes disciplines whose focus of enquiry concerns either living things or inanimate objects.

However, these distinctions can become problematic when considering the difference between creative arts and STEM subjects. The sciences (broadly speaking) examine both living things (e.g. biology) and the inanimate (e.g. physics), and similarly the focus of artistic enquiry could be on any subject or object at all. Moreover, the distinction between pure and applied is also problematic. It could be argued that artistic work always constitutes pure knowledge, as the act of novel creation is central to the artistic process. However, it could just as easily be argued that artistic work is always applied, using or adapting existing methods, techniques and concepts and applying them to new areas of focus. Similarly, the sciences encompasses both pure and applied forms of almost any scientific discipline.

A second approach, which speaks more to Biglan's distinction between hard and soft disciplines, is that of Maton (2013) who, building on Bernstein (2000), argues that disciplines can be distinguished by their structures of knowledge and knowers, or epistemic and social dimensions. In specific reference to Snow's two cultures (2012 [1959]), Maton argues that a key distinction between arts and science based disciplines is in their *specialisation codes* or what constitutes expertise. He argues that in science based disciplines, the basis of specialisation relies upon its languages being discursively different to common understandings – it is the knowledge which is specialised, and expertise is conferred through accumulation of specialised language knowledge. By contrast, the arts are portrayed as requiring less specialised languages, and emphasis is placed on knower structures, where specialisation and authority result from social hierarchies and expertise is conferred through personal attributes.

As such, we can think of the difference between arts based disciplines and science based disciplines as encompassing differences in structures of knowing, with the sciences utilising more paradigmatic ontologies and expertise being conferred through greater understanding of these paradigms, whereas the arts utilise greater plurality of ontology, where expertise is conferred through personal justification. In other words, the sciences rely on investigation of the world through the scientific method (paradigmatic ontologies), whereas the arts rely on investigation of the world through application of personal experience. Thus the tools of scientific enquiry and artistic enquiry differ, though both can be used to advance knowledge of almost any topic.

As such, when investigating the fusion of creative art and STEM skills, we are investigating the fusion of different methods of advancing knowledge, either through more positivistic experiment and application or through more pluralistic creating and interpretation. Thus, the thesis defines fusion as *the combination of information and proficiencies (skills) arising from different methods of advancing knowledge (arts and sciences), that are embedded within an individual, group or organisation and embodied through action.*

Finally, what is clear from the introduction to the concept of fusion at the beginning of this chapter and from the preceding explanations of how fusion can be conceptualised, is that the fusion of artistic and scientific skill can be applied to varying units of analysis. Thus: i) an individual may have skills in both creative arts and STEM (individual level fusion), ii) a group, organisation or firm may include some individuals with creative arts skills and some individuals with STEM skills (firm level fusion), or iii) a group, organisation or firm may predominantly include individuals with either creative arts or STEM skills, but may work alongside another group, organisation or firm which is predominantly constituted by individuals representing the alternative skillset (inter-firm level fusion). Consequently, the broad definition of fusion used in this thesis necessitates multiple units of analysis, leading to a conception of fusion as a necessarily multi-level construct.

The application of multi-level approaches to studying organisations has been steadily growing since the mid 1980s (Klein et al., 1999; Mathieu & Chen, 2011; Carter et al., 2015; Molina-Azorín et al., 2020). Extant work has examined a wide range of organisational phenomena from a multi-level perspective, including competency building (Loufrani-Fedida & Missonier, 2015), trust (Currall & Inkpen, 2002; Fang et al., 2008), social capital (Zhang et al., 2020) and knowledge integration processes (Bhandar, 2008). Here it is argued that organisations exist in a nested structure, with individuals at the centre, who are nested within working groups, which are nested within departments or business units, which are nested within organisations, which are themselves nested within networks of inter-organisational relationships (Hitt et al., 2007). It is the interplay of relationships and practices both within and between these different levels which cumulatively impact firm level performance (Moliterno & Mahony, 2011).

In relation to skills specifically, Ployhart and Moliterno (2011) argue that in understanding how human capital shapes firm performance, scholars must seek to understand both individuals' knowledge, skills and abilities, and the mechanisms through which these individual level traits are utilised and transformed by teams and organisations. Moreover, organisations operate within networks of other firms, collaborating, sharing knowledge and learning from one another, meaning that a firm's competencies are impacted by the competencies of other firms in its network (Molina-Azorín et al., 2020).

Consequently, in regarding fusion as a multi-level construct, we are better able to connect the micro, meso and macro interactions that constitute fusion and bridge perspectives to create a more wholistic understanding of fusion than has been previously achieved. The next section of this chapter goes into greater detail in describing how each level of fusion, or unit of analysis, is theorised.

1.4.2. Theoretical lenses

This thesis examines the concept of creative arts and STEM skills fusion at three levels: the level of the individual, the firm and inter-firm. Different levels of analysis often confer different theoretical lenses to help understand the phenomena in question. This section of the thesis will explain the differing theoretical lenses – multi/inter disciplinary education, knowledge integration and combinatorial knowledge bases – that the thesis applies to the concept of fusion. It will explain why each lens is productive for understanding fusion at that level of analysis and how these differing theoretical approaches can be utilised collectively to gain a greater understanding of fusion in practice. The section does not explain each theoretical lens in extensive detail, as this can be found in chapters 2, 3 and 4, but offers the reader an explanation of how and why these different approaches have been taken.

Multidisciplinarity and Interdisciplinarity

Some of the most prominent work on the fusion of creative arts and STEM skills comes from the education literature. Here there have been longstanding calls for better integration of the arts and sciences more broadly, and much work has specifically focused on the benefits of combining arts and STEM learning – the so called ‘STEAM’ agenda (Bequette & Bequette, 2012; Daugherty, 2013; Colucci-Gray et al., 2017; Cultural Learning Alliance, 2017). Rallying against increased policy prioritisation of STEM subjects since the early 2000s (Blackley & Howell, 2015), STEAM advocates argue that arts based pedagogies enhance creativity and imagination and evidence that integrating such pedagogies with STEM curricula fosters divergent thinking, metacognitive skills and collaboration capabilities (Land, 2013; Ghanbari, 2015; McAuliffe, 2016; Sochacka et al., 2016). In this vein, discourses around STEAM education have drawn upon longstanding theorisations of the benefits of multidisciplinary and interdisciplinary education practice (Colucci-Gray et al., 2019).

Multidisciplinarity refers to when a given object of study is approached from two or more separate perspectives. Here contrasting methodologies, ontologies, theories and perspectives are used, but within recognisably delineated disciplinary paradigms (Darbellay, 2015). This type of education can be beneficial as it exposes students to multiple disciplinary languages, ontologies and modes of learning with delineated structures (Moss et al., 2003). On the other hand, interdisciplinarity involves the active integration of disciplinary knowledges. Here connections are made between disciplinary based ideas, synthesising, blending or linking between methodologies, ontologies, theories and perspectives. Interdisciplinary learning can be beneficial as it encourages students to identify links and connections between different bodies of knowledge (Lattuca et al., 2004; Borrego & Newswander, 2010). Thus, multidisciplinary education offers opportunity for students to learn multiple disciplinary languages and ‘thought worlds’, enabling them to view a problem from contrasting standpoints, and interdisciplinary education offers opportunity for students to learn connections and synergies between disciplines, enabling them to effectively synthesise ideas from diverse areas of knowledge (Klein, 1996). Thus the multi/inter disciplinary literature reminds us that education systems do not simply impart declarative and tacit knowledges, but they socialise individuals into ways of understanding the world and shape identity formation. Education constitutes multiple aspects of socialised practice, as individuals become enculturated into the modes, methods and thought processes of their respective disciplines (Rosch & Reich, 1996). Each discipline has its own “webs of belief” which must be adopted by the student in order for them to succeed in that context and in this way students’ educational experience shapes how they learn and their criteria for validating knowledge (Brown et al., 1989, p.4).

As mentioned in the previous section, valorisation of specialisation as the antecedent to economic growth has seen education systems in the UK and elsewhere being a driving force in the training of highly specialised individuals (Skorton & Bear, 2018). In seeking to understand how fusion occurs in the creative industries, it is therefore important to question the extent to which creative industries workers have specialised educational pathways, or whether they have engaged in education from multiple disciplinary standpoints. By understanding individual level fusion as both multidiciplinary and interdisciplinary educational background, we begin to understand how fusion can be constructed within an individual as opposed to between individuals. Additionally, taking a multi/inter disciplinary lens to the concept of fusion, introduces notions of socialisation and identity, alongside issues of specialist knowledge, language and modes of learning that are all integral aspects of what it is to be fused and will be revisited throughout the thesis at each of the levels under examination.

Knowledge integration

At the team, group or firm level, what this thesis refers to as fusion is often conceptualised in relation to cross functional working and ideas around team diversity. Studies have found that greater innovation occurs when teams encompass greater diversity of education type (Wiersema & Bantel, 1992) or functional background (Bantel & Jackson, 1989). However, other studies have shown diversity to result in greater conflict and less effective teamwork (Pelled et al., 1999) and in other studies diversity has been shown to have no significant effect at all (Sethi et al., 2001). This disparity in findings suggests that there are likely to be intervening variables in this relationship which can explain why diversity of functional background and education specialisation have mixed effects on innovation. Ancona and Caldwell (1992) found that whilst functional diversity had a negative effect on team performance and team level innovation, it was associated with increased communications outside of the team, which did in turn encourage innovation at the firm level. Alternatively, Fay et al. (2006) found that functionally diverse teams were associated with greater innovation, but only when ‘shared vision’ and high interaction frequency were present. Similarly, Simons et al. (1999) found that functional heterogeneity was beneficial only when teams engaged in open debate. Accordingly, systematic reviews of diversity literature argue that functional diversity in teams does increase innovation, but that the effectiveness of diverse groups is contingent on contextual conditions that mitigate the risks of incohesive teamwork (Milliken & Martins, 1996; Williams & O’Reilly, 1998; Horwitz & Horwitz, 2007). In this vein, West proposes that "knowledge and skill diversity in groups fosters innovation", but that this must be facilitated by strong integration processes (West, 2002, p.365). As such, much literature has focused on how firms can maximise the innovative potential of a diverse workforce, whilst minimising the potential conflict that such groupings can produce.

So what is actually happening when a group of people from different functional backgrounds come together? Essentially, fusion in this context can be seen as knowledge integration, where people who possess differing knowledges usefully combine these knowledges to creative new knowledge (Okhuysen & Eisenhardt, 2002; Berggren et al., 2011; Tell, 2011). Within this paradigm, the fusion of knowledge is a deeply social process (Kogut & Zander, 1992) and knowledge in this context encompasses declarative knowledge, tactic knowledge, specialist languages, perspectives, identities etc. – in other words, the culmination of education and experience. While viewing fusion through an education lens begins to shed light on how these knowledges are formed within individuals, by examining fusion through a knowledge integration lens we can begin to understand how fusion between individuals with different skills takes place. Thus, this framework is useful for exploring fusion between individuals as opposed to within individuals. Moreover, through examination of fusion as an issue of knowledge integration, we begin to address some of the challenges faced in fusion. For example, in addressing issues of conflict raised in the diversity literature, a knowledge integration lens highlights the importance of trust (Rauniar, 2005; Willem et al., 2008; Bhandar, 2010; Erkelens et al., 2010), motivation (Carlile, 2002, 2004; Enberg et al., 2006; Adenfelt & Maaninen-Olsson, 2007; Bhandar, 2010), identity (Kogut & Zander, 1996; Grandori, 2001; Ordanini et al., 2008; Willem et al., 2008; Erkelens et al., 2010; Liu & Phillips, 2011; Ahuja & Sinclair, 2012) and social capital (Huang & Newell, 2003; Newell et al., 2004; Frost & Zhou, 2005; Bhandar et al., 2007; Bhandar, 2010).

In understanding the challenges associated with functionally diverse teams as issues of knowledge integration, rather than issues of diversity per se, we move away from notions of inherent difference and move towards consideration of these challenges as issues of process. As such, conceiving of fusion as knowledge integration steps away from the perspective advanced by considering fusion in relation to academic disciplines, and moves towards an understanding of fusion as between anyone with disparate knowledge.

Combinatorial knowledge bases

In addressing fusion at the inter-firm level, there is a wide literature in economic geography surrounding the idea of related and unrelated diversity. Much of this work builds on the idea that firms have heterogonous resources and capabilities (Penrose, 1995) and that inter-firm collaboration is an effective means to access resources and capabilities beyond the boundaries of the firm (Eisenhardt & Schoonhoven, 1996). However, the extent to which firms will be able to utilise external knowledge is reliant on their absorptive capacity, or the ability of a firm to acquire, assimilate, transform and exploit external knowledge (Zahra & George, 2002). If a firm has prior knowledge in a similar area to the new knowledge, it will be easier for a firm to seek out, understand and use the new knowledge (Cohen & Levinthal, 1990). Thus, much literature suggests that knowledge relatedness is central to the ability of firms to collaborate and integrate knowledge across institutional and sectoral boundaries (Mowery et al., 1996; Lane & Lubatkin, 1998). Following this line of reasoning, firms can benefit from collaboration as it extends their capabilities (unrelated variety), but issues of absorptive capacity will mean that firms are able to gain external knowledge more effectively from firms who operate within a similar knowledge field to their own (related variety). As such, in inter-firm level fusion we see similar arguments to those being made at the firm level, that knowledge diversity – or, in this strand of research, ‘cognitive proximity’ – must strike a balance between the benefits of drawing on and combining multiple knowledges and the challenges of communication and absorption of that knowledge (Boschma, 2005).

An alternative approach however is offered by the combinatorial knowledge bases (CKB) literature (Asheim, 2007; Asheim et al., 2017). In this body of work, “innovation outputs ultimately relate to underlying knowledge dynamics, including the type of knowledge used in innovation processes, the routines to generate new knowledge, and the actors involved in innovation processes” (Grillitsch et al., 2019, p.236). Consequently, this strand of research asserts that firms benefit from collaboration not simply by gaining additional resources and capabilities, but by combining different “learning modes, approaches to reasoning and criteria for validation of knowledge” (Manniche et al., 2017, p.453).

By drawing on theoretical approaches from economic geography, we can therefore conceptualise fusion at the inter-firm level as a combining of knowledge bases, or ways of learning and constructing knowledge. This conceptualisation draws again on notions of disciplinary focus, in that is speaks to differences in paradigms, methods and the value of differing types of knowledge – e.g. quantitative vs qualitative, basic vs applied etc. As such, it offers a more nuanced approach to understanding inter-firm collaboration than one focusing solely on resource and capability development and furthers our understanding of fusion at this wider level by revisiting some of the issues highlighted in the education and management literatures.

1.4.3. Conceptual framework

To summarise, at the individual level, fusion is framed in relation to education. By using an education lens to examine skills fusion we begin to gain an understanding of how education imparts not only declarative and tacit knowledge but enculturates individuals into ways of viewing the world. Moreover, by viewing fusion within an individual as an issue of multi/inter disciplinary, we find a strong theoretical argument for why fused individuals may be more able to contribute to innovation by drawing on multiple paradigms and areas of expertise and being able to effectively bridge between different ways of viewing the world. At the firm level, fusion is framed in relation to cross-functional teamwork and knowledge integration. This approach is apt for addressing fusion between individuals, as it highlights the challenges and benefits of combining disparate knowledges in practice. Moreover, by using a knowledge integration lens to look at fusion at the firm level, we can explore further the idea of differing forms of knowledge and specifically address fusion in relation to innovation. At the inter-firm level, fusion is framed in relation to inter-firm collaboration and combinatorial knowledge bases. By using a CKB framing to look at fusion at the inter-firm level, we reconstruct some of the notions of identity and specialisation touched upon in the previous approaches and apply them to the firm itself. This approach draws on concepts such as absorptive capacity and related variety to further explore what is different about firms operating in different industry sectors. As such, by utilising this framework we can gain an understanding of fusion as being about differing approaches to learning, knowledge creation and knowledge validation.

There are many common themes running through these three approaches to the concept of fusion. The most prominent theme is perhaps the idea that diversity is a trade-off, or balancing act, with increased diversity being beneficial for innovative knowledge formation, but also introducing challenges of communication and bridging between differing frames of reference and values. At the individual level, in the education literature, this trade-off is framed as the benefits of developing different ways of thinking and exposure to multiple paradigms versus the benefits of acquiring a greater depth of knowledge in a particular subject (Nissani, 1997; Chettiparamb, 2007). At the firm level, within knowledge integration literature, this is framed as the balance between ensuring sufficiently diverse knowledge so as to increase the repertoire that can be drawn upon in innovation and the need for sufficient common knowledge to aid the knowledge integration process (Postrel, 2002; Mengis et al., 2009). At the inter-firm level, within the CKB literature, we see the argument being framed in relation to the benefits of differing approaches to innovation versus a firm's ability to absorb knowledge from different knowledge domains (Boschma, 2005). This idea of diversity as a trade-off is addressed extensively in chapter 3 and revisited in the discussion in chapter 5.

The second common theme each of these theoretical lenses shares is an epistemological view of knowledge as practice (as mentioned in the preceding section), whereby possession of knowledge is delineated from knowing, which is the active practice of performing an action in context (Cook & Brown, 1999). With this focus on knowledge as knowing, we move away from the idea of "knowledge as a kind of economic asset or commodity" which can be easily acquired, transferred and possessed, towards an understanding of knowledge as a deeply social accomplishment (Spender, 1996, p.54). This is important as knowledge is not seen as fixed, but rather as a constantly emerging phenomena and therefore the fusion of knowledge at each level of investigation can be seen as an active process of combination and recombination of disparate ways of approaching a task. Through this understanding, issues of learning, social capital, culture, community and identity are highlighted in each of the three approaches taken in the thesis.

From this brief introduction to the three main approaches used in the thesis, we can see how fusion can be framed in different ways according to the level in which it is examined and the disciplinary gaze under which it has been scrutinised. However, we can also see how the core conceptualisations of fusion are commensurable across the approaches, yet are framed differently in relation to the languages and empirical focus of the disciplines involved in investigating them. Table 3 below summarises each of these approaches and the manner in which they are used in this thesis to operationalise fusion.

Table 3 – Approaches to fusion

Level	Disciplinary focus	Theoretical lens	Empirical focus	Conceptualisation of fusion	Operationalisation
Individual	Education	Multi/inter disciplinarity	Discipline	Skills – knowledge formation	Creative arts and STEM qualifications
Firm	Business management	Knowledge integration	Functional background	Knowledge – knowledge utilisation	Creative and Technical functional background
Inter-firm	Economic geography	Combinatorial knowledge bases	Industry	Knowledge bases – ways of learning	Symbolic and analytic/synthetic knowledge base

In seeking to understand fusion as a multi-level construct, this thesis draws on each of the three approaches outlined above. In doing so, it seeks not to delineate or compartmentalise fusion, but rather to forge a coherent theory of fusion built upon the synthesis of these constituent parts. By drawing on multiple disciplinary understandings of fusion, the thesis itself offers an example of fusion, juxtaposing and incorporating differing approaches to knowledge and learning. As such, we can gain a more nuanced understanding of fusion by examining the multiple issues involved at differing levels of analysis. Moreover, by taking distinctly different disciplinary perspectives, the thesis not only contributes to multiple literatures but demonstrates points of intersection between discrete areas of study.

1.4.4. Research design

This thesis takes a mixed methods approach to its investigation of the fusion of creative arts and STEM skills in and around the UK creative industries. As the thesis examines fusion at the individual, firm and inter-firm levels, each level of examination necessitates different empirical contexts and theoretical framing. As such, it is also apt to vary the methodological approach to best suit each unit of analysis.

Chapter 2 examines fusion at the individual level, framing fusion in relation to multi/inter disciplinary education. It aims to address RQ1: What is the relationship between STEAM education and graduate employment outcomes in the UK creative industries? Here a quantitative approach is taken based on analysis of graduate outcomes data from the Higher Education Statistics Agency (HESA). This dataset is critical in understanding the link between education and employment as it is the only dataset which includes information about all graduates from UK further and higher education which also links this education to employment in specific sectors of the economy[7]. By using this dataset we therefore gain an understanding of the employment prospects for graduates who have a fused education profile – i.e. have studied a combination of creative arts and STEM subjects across further and higher education levels – specifically within the creative industries. Analysis of this data includes both descriptive statistics and econometric analysis. Descriptive statistics are used to identify the amount of fusion in the graduate population and the general outcomes of these students, giving an indication of the relative merits of a fused skillset in relation to employment outcomes. Probit regressions are then used to assess the extent to which graduates who have a fused skillset are more likely to work in the creative industries than those who do not, demonstrating a clear link between multi/inter disciplinary education and work in this sector.

Chapter 3 examines fusion at the firm level, framing fusion in relation to knowledge integration. It aims to address RQ2: How does the interplay of different forms of common and diverse knowledge shape processes of knowledge integration? As knowledge integration processes are deeply complex, social, and context specific phenomena, a qualitative approach is most suited to gaining an understanding of such processes (Tell, 2011). Moreover, as knowledge integration can be seen as “inseparable from its context” (Yin, 1981, p.99), a singular case study has been used to gain a depth of understanding of knowledge integration processes which would not have been possible using a different approach. Whilst case study designs have been criticised for their lack of generalisability, it is widely acknowledged that an ‘instrumental’ approach to case study methodology (Stake, 1995) means that cases can be used to ‘facilitate’ understandings of wider practice (Baxter & Jack, 2008) and to build theory (Eisenhardt, 1989). The case study used in this chapter is situated in one of the largest visual effects companies in the UK. The visual effects industry was chosen as it relies heavily on employees from a wide variety of backgrounds, ranging from those who studied fine art

[7] The Longitudinal Education Outcomes (LEO) dataset also offers graduate outcome data, however currently this data is not linked to employment at an industry level.

to those with advanced physics degrees (Livingstone & Hope, 2011) and requires inter-disciplinary, cross-functional teamwork where diverse knowledge from multiple domains is incorporated into a single 'product' – the film (Spelthann & Haunschild, 2011; Seymour & Coyle, 2016).

Chapter 4 examines fusion at the inter-firm level, framing fusion in relation to combinatorial knowledge bases. It aims to address RQ3: To what extent is innovation policy in the UK supporting creative industries firms in engaging in formal R&D collaborations with firms from STEM sectors and how do such collaborations differ to projects which involve less sectoral variety? Here again a quantitative approach was taken, using official datasets, in order to provide insights that speak to a broad UK context. The dataset used for this chapter is comprised of all collaborative R&D grant awards made by the UK government via its innovation agency InnovateUK, between 2004 and 2020 (Innovate UK, 2020). Through analysis of this dataset we are able to gain understanding of how innovation policy in the UK is supporting inter-firm level fusion through the funding of collaborative R&D projects. This chapter conducts two main areas of analysis. Firstly, descriptive statistics detail the extent to which creative industries firms are present in the data and some characteristics of the projects which creative industries firms are involved in, including both summary statistics and network visualisations depicting the interrelation of firms within projects. The second area of analysis focuses on fused projects, outlining the main differences between fused and unfused projects in relation to project size, length and cost. The characteristics of fused projects are further examined using probit regressions at both the project and the participant level.

By using large scale datasets to examine fusion at the individual and inter-firm level, the thesis offers evidence as to the value of fusion to the creative industries. By taking a more in-depth qualitative approach to fusion at the firm level, the thesis develops theory that helps us understand how disparate knowledges can be integrated. Much like the substantive focus of the thesis itself, by taking differing yet complimentary methodological approaches to the investigation of fusion in the creative industries we can gain a more rounded understanding of the phenomena.

1.5. Contributions

Each of the papers presented in this thesis offer significant contributions to practice, policy and/or theory.

Paper 1 (chapter 2) offers empirical evidence of the link between individuals with a fused skillset and work in the creative industries. Whilst there has been work which assesses employment outcomes for those studying creative arts subjects and those studying STEM subjects in higher education, there has been little research to date which explicitly considers graduates with an education that combines both skillsets. In gaining a greater understanding of the prevalence of fused graduates in the creative industries, the paper takes an important step in beginning to unpack the findings of studies which have considered fusion at the firm level (Sapsed et al., 2013; Siepel et al., 2016, 2019) by indicating the extent to which 'fused firms' may be being supported by fused individuals who act as boundary spanners between diverse mono-specialists. Moreover, by taking into account both pre-HE and HE qualifications in determining a graduate's skillset, this paper creates a novel and robust metric for assessing skills fusion at an individual level. This metric can be used to benchmark individual level fusion and can be easily replicated by future researchers.

Paper 2 (chapter 3) explores fusion at the firm level and presents a novel theoretical framework which explicates the interplay of common and diverse knowledge in processes of knowledge integration. By applying this framework in the visual effects industry, the paper demonstrates that it is possible to have common knowledge in some areas, and to have knowledge diversity in other areas. Moreover, the paper demonstrates that the interplay of these different forms of common and diverse knowledge shape how knowledge is integrated and new knowledge is formed. In providing a theoretically driven taxonomy of different knowledge types, the paper significantly contributes to extant theory by expanding our conceptualisation of common knowledge to specifically include the interplay of different knowledge types. As such, the paper furthers theoretical understandings of the relationship between common and diverse knowledge by problematising the notion that common knowledge is a singular entity and that commonality and diversity exist on a singular spectrum.

Paper 3 (chapter 4) contributes to extant literature by firstly offering evidence as to the extent of creative industries involvement in publicly funded R&D collaborations in the UK. This is important in understanding the impact of innovation policy at a national level and in identifying ways in which such policy could be better targeted towards creative industries firms. Additionally, the paper contributes to the burgeoning distributed knowledge bases literature, by exploring the characteristics of collaboration projects which combine knowledge bases in formal R&D programmes. This element of analysis furthers our understanding of knowledge base combinations, by investigating their characteristics in the context of publicly funded R&D programs and can inform the design of innovation policy to better capitalise on the benefits of knowledge base combinations.

Overall, the thesis makes a significant original contribution to knowledge by first defining and then expanding upon a definition of fusion as a multi-level construct. Prior work on fusion has tended to focus solely on one level of analysis – the individual, firm or inter-firm. However, by incorporating theories of fusion from differing disciplines to examine fusion at each key level of analysis, the thesis contributes a more extensive investigation of the notion of fusion than has previously been achieved. As such, examination of the concept of fusion presented in this thesis significantly contributes to theorisations of the notion, extending our knowledge of how fusion operates and developing theory and methods that advance investigation of the concept.

2. Mono-specialists and Trans-specialists in the Creative Industries: Mapping Creative Arts and STEM Skills Fusion in the UK Graduate Workforce[8]

Abstract: This paper maps the prevalence of UK graduates who have studied a mixture of creative arts and STEM (Science, Technology, Engineering and Mathematics) qualifications and assesses their likelihood to enter the creative industries. Using data from the Higher Education Statistics Agency (HESA), a metric for 'skills fusion' is constructed which takes into account the disciplinary mix of a student's educational qualifications across further education and higher education. Employment outcomes are then assessed for students who have studied a combination of creative arts and STEM subjects, who are referred to as 'fused' graduates. The paper finds that fused graduates are significantly more likely to be employed in the creative industries than most other graduate groups. This suggests that the fusion of creative and technological skills, found elsewhere to be beneficial at firm level, may be being supported by skills fusion at the individual level, where fused individuals act as boundary spanners between diverse mono-specialists. However, the paper also finds that the UK higher education landscape offers little opportunity for students to develop multidisciplinary and interdisciplinary skillsets, with only 1% of graduates studying a combination of creative arts and STEM subjects at degree level. Consequently, the findings of this study contribute to our understanding of the role of fused individuals in the creative industries workforce and the provision of multidisciplinary and interdisciplinary STEAM (STEM+Arts) provision in UK higher education.

Keywords: Creative Industries; Education; Interdisciplinarity; Skills; STEAM

2.1. Introduction

This paper brings together concepts from management literature surrounding the importance of boundary spanners in interdisciplinary working, and concepts from education literature surrounding multidisciplinary and interdisciplinary learning, to investigate the link between studying a combination of creative arts and STEM (science,

[8] Data supplied by HESA – Sources: HESA Student Record 2012/13; HESA DLHE Record 2012/13; HESA DLHE Long Record 2012/13. Copyright Higher Education Statistics Agency Limited. Neither the Higher Education Statistics Agency Limited nor HESA Services Limited can accept responsibility for any inferences or conclusions derived by third parties from data or other information supplied by HESA Services.

technology, engineering and mathematics) subjects in Further Education (FE) and Higher Education (HE), and future employment in the creative industries.

The creative industries increasingly require both creative arts and STEM skills (Docherty, 2010; Bakhshi et al., 2013; Sleeman & Windsor, 2017). Further, it has been shown that combining creative arts and STEM skills in creative industries firms leads to greater innovation and firm growth (Sapsed et al., 2013; Siepel et al., 2016, 2019). As such, many recruiters in the creative industries seek candidates whose skillsets sit at the intersection of creative art and STEM (Sleeman & Windsor, 2017), as these employees are able to act as 'boundary spanners' between the two disciplines. However, despite evidence that 'fusing' creative arts and STEM skills is beneficial for the creative industries and evidence that creative industries firms are increasingly seeking to recruit individuals with 'fused skillsets', evidence of the prevalence of fused individuals in the UK creative industries remains sparse. Thus, in order to support policy aimed at developing the types of skills needed in the creative industries, this paper provides evidence as to the levels of 'skills fusion' in the graduate population, and across the creative industries in the UK.

Whilst previous studies have gone some way to explicate the relationship between higher education and graduate employment in the creative industries, there is yet to be work which considers skills combinations in this context. Moreover, there is yet to be work which considers the impact of both higher education and further education in assessing graduate outcomes. In addressing this gap, the paper develops a novel metric for assessing creative arts and STEM fusion at the individual level, using graduate data from the University and Colleges Admissions Service (UCAS) and the Higher Education Statistics Agency (HESA). It then uses this metric to map the prevalence of skills fusion in the UK graduate population and to assess the likelihood of these graduates becoming employed in the creative industries.

In doing so, the paper advances our understanding of the types of skills utilised in the creative industries and provides the basis to explore the fusion of creative arts and STEM skills at a more granular level than has previously been achieved. Consequently, the paper contributes much needed evidence to support the formation of skills policy targeted towards the creative industries. Moreover, by considering the impact of multidisciplinary and interdisciplinary education in training future boundary spanners, the paper contributes to both management and education literatures. With the increasing importance of the creative industries, there is a growing body of work which insists that investment in both creative and technological skills is imperative for the continued growth of the creative sector. The findings of this paper add further voice to such a chorus, by demonstrating the importance of multidisciplinary and interdisciplinary creative arts and STEM fusion to the creative industries.

The paper is organised as follows: section 2.2. summarises prior work surrounding fusion in the creative industries, the importance of boundary spanners to facilitate such interdisciplinary working, and the UK higher education landscape in regards to multidisciplinary and interdisciplinary education. Section 2.3. then describes the data and methods used for analysis. Section 2.4. presents the paper's findings, which are then discussed in section 2.5., alongside policy recommendations, limitations of the study and possibilities for future research.

2.2. Context

2.2.1. The UK creative industries and the fusion of creative arts and STEM skills

The creative industries are one of the fastest growing sectors in the UK, in terms of both employment and Gross Value Added (DCMS, 2019a). As such, the UK Industrial Strategy has highlighted the creative industries as a priority area, and the subsequent Creative Industries Sector Deal has been developed in an attempt to promote continued growth of the sector (HM Government, 2017, 2018). One of the main challenges identified in these reports are an increased need for appropriate skills. Grey literature reports have long argued that both private and public investment in skills for the creative industries is necessary to ensure the economic sustainability of this increasingly important sector (DCMS, 2008; Livingstone & Hope, 2011; Bakhshi et al., 2013; Creative Industries Council, 2014; Creative Skillset, 2014; Bakhshi & Windsor, 2015; Dass et al., 2015; Neelands et al., 2015; Creative Industries Federation, 2016; Windsor et al., 2016; Bazalgette, 2017). For example, a recent nationwide survey of the sector found 42% of creative industries firms reported skills issues, including not being able to recruit staff with appropriate skills or their current staff lacking appropriate skills (Bakhshi & Spilsbury, 2019).

So what skills are required to work in the creative industries? The creative industries (as the name suggests), rely heavily on creative and artistic talent (Bloom & Bakhshi, 2020). However, many subsectors of the creative industries, such as software design and videogames, are highly technological, requiring advanced STEM training (Sleeman & Windsor, 2017). Moreover, over the last century we have seen an increasing convergence of art and technology across all subsectors of the creative industries, (Bakhshi et al., 2012; Hesmondhalgh, 2018), with new and more pervasive technologies creating opportunities for new products, new processes and new markets for creative goods and services (Davies & Ward Dyer, 2019). Both creative and STEM specialists are therefore highly important to creative sectors. However, these skills are not only of use in isolation. It has been shown that the benefits of utilising creative arts and STEM specialists is only fully actualised when these specialisms are used in combination with each other (Brunow et al., 2018; Siepel et al., 2019). This is particularly the case for creative industries firms, where those that combine, or 'fuse', creative and STEM knowledges have higher employment growth, higher sales growth, and are more innovative than firms that utilise only one of these skillsets (Sapsed et al., 2013; Siepel et al., 2016).

The importance of interdisciplinarity to the creative industries is also reflected in the structure of the sector. The creative industries encompass a wide range of different subsectors, from the more traditional arts base of performance and fine art, to software and computing services. While diverse in output, these subsectors have been shown to have dense collaboration and value chain networks (Mateos-Garcia & Bakhshi, 2016; Gundolf et al., 2018; Hesmondhalgh, 2018). Moreover, the creative industries have a high proportion of small and micro organisations which are frequently supported by freelance workers (McKinlay & Smith, 2009; Jones et al., 2015; Virani & Pratt, 2015) and, as much creative work is project based, temporary organisations and flexible networks are common (Starkey et al., 2000; Lampel & Shamsie, 2003; Daskalaki, 2010). This means that much creative work occurs through collaboration and knowledge sharing between organisations and individuals with widely varied skills and knowledge sets. Moreover, within creative SMEs, organisational structures are typically flat and heterarchical, with teams and working groups generally forming around projects as opposed to functional divisions (Grabher, 2001; Spelthann & Haunschild, 2011; DeFillippi, 2015). Consequently, the creative industries are a sector characterised by a reliance on "blended technical and creative skills [alongside] collaborative interdisciplinary working" (Bazalgette, 2017, p.4).

2.2.2. Generalists versus specialists – the importance of boundary spanners

While creative arts and STEM fusion has been shown to lead to innovation in the creative industries, interdisciplinary working presents a range of challenges. Interdisciplinary working can strengthen a firm's innovation capabilities by increasing the repertoire of knowledge that can be drawn upon in developing new products and services and increasing the opportunities for novel combinations of knowledge to emerge (Schumpeter, 1934; Cohen & Levinthal, 1990; Kogut & Zander, 1992). However, in order for the innovative benefits of interdisciplinary working to materialise, significant challenges in regards to communication and teamwork must be overcome (Milliken & Martins, 1996; Williams & O'Reilly, 1998; Horwitz & Horwitz, 2007). Interdisciplinary working can be challenging as it requires bridging differences in language, working practices and 'thought worlds' (Bechky, 2003; Carlile, 2004; Nooteboom et al., 2007; Mengis et al., 2009). As such, although interdisciplinary teams have been found to be highly innovative, they have also been found to encounter conflict and less efficient teamwork (Ancona & Caldwell, 1992; Pelled et al., 1999; Fay et al., 2006).

One of the ways in which the difficulties of interdisciplinary working can be mitigated is through the use of 'boundary spanners'; teams or individuals who sit at the intersection of different knowledge domains and are able to bridge the gap between disciplinary or functional groups (Marrone, 2010). Such boundary spanners can act as knowledge brokers, "transferring ideas from where they are known to where they represent innovative new possibilities" (Hargadon, 1998, p.214). Boundary spanning between disparate experts has been shown to be a key ingredient in successful creative activity in sectors such as design (Hargadon & Sutton, 1997), film (Kirby, 2008; Foster et al., 2015), music (Lingo & O'Mahony, 2010), television (Starkey et al., 2000), publishing (Boari & Riboldazzi, 2014), and theatre (Uzzi & Spiro, 2005). Within the context of creative work, boundary spanners "do not just transfer, share, or broker ideas, they must incorporate them into a creative product" (Lingo & O'Mahony, 2010, p.50). Moreover, as much work in the creative industries is highly specialized, effectively bridging the 'cognitive gap' between diverse experts and diverse areas of knowledge requires a certain amount of 'trans-specialist' knowledge, or knowledge of multiple disciplines (Tell et al., 2017, p.5).

Consequently, it can be contended that 'fused individuals' – trans-specialists trained in both creative arts and STEM disciplines – are likely to play an important bridging role between artistic and technological domains, acting as boundary spanners between creative arts and STEM specialists, and facilitating knowledge integration, teamwork and creativity. In the context of the creative industries then, the ideal type innovative firm will want to employ both creative arts and STEM specialists, and the fused trans-specialists necessary to effectively exploit these seemingly disparate skills.

2.2.3. Multidisciplinary, interdisciplinarity and the UK education system

Some of the most prominent work on the fusion of creative arts and STEM skills comes from the education literature. Here there have been longstanding calls for better integration of the arts and sciences more broadly, and much work has specifically focused on the benefits of combining arts and STEM learning – the so called 'STEAM' agenda (Bequette & Bequette, 2012; Daugherty, 2013; Colucci-Gray et al., 2017; Cultural Learning Alliance, 2017). Rallying against increased policy prioritisation of STEM subjects since the early 2000s (Blackley & Howell, 2015), STEAM advocates argue that arts based pedagogies enhance creativity and imagination and provide evidence that integrating such pedagogies with STEM curricula fosters divergent thinking, metacognitive skills and collaboration capabilities (Land, 2013; Ghanbari, 2015; McAuliffe, 2016; Sochacka et al., 2016). In this vein, discourses around STEAM education have drawn upon longstanding theorisations of the benefits of both multidisciplinary and interdisciplinary education practice (Colucci-Gray et al., 2019).

In relation to both working practices and education systems, it is important to note a subtle but important distinction between multidisciplinarity and interdisciplinarity (Meeth, 1978). Multidisciplinarity refers to when a given object of study is approached from two or more separate perspectives. Here contrasting methodologies, ontologies, theories and perspectives are used, but within recognisably delineated disciplinary paradigms (Darbellay, 2015). In the context of education, this might mean students enrolling on separate courses with different disciplinary foci. This type of education can be beneficial as it exposes students to multiple disciplinary languages, ontologies and modes of learning with delineated structures (Moss et al., 2003). Interdisciplinarity however, involves the active integration of disciplinary knowledges. Here connections are made between discipline-based ideas, synthesising, blending or linking between methodologies, ontologies, theories and perspectives (Klein, 2010). In regards to education, this might translate as single courses which combine knowledge and learning styles from two or more different disciplines. Interdisciplinary learning can be beneficial as it encourages students to identify links and connections between different bodies of knowledge (Lattuca et al., 2004; Borrego & Newswander, 2010). Thus, multidisciplinary education offers opportunity for students to learn multiple disciplinary languages and 'thought worlds', enabling them to communicate effectively with specialists from multiple disciplines, and interdisciplinary education offers opportunity for students to develop connections and synergies between disciplines, enabling them to effectively synthesise ideas from diverse areas of knowledge (Klein, 1996).

Both multidisciplinary and interdisciplinary approaches to research have gained traction in academia over the last century as they are seen as best able to tackle emergent and complex issues which cannot be resolved through one approach alone. In pedagogy too, multidisciplinary and interdisciplinary approaches have been incorporated into teaching of both undergraduate and postgraduate courses (Chettiparamb, 2007; Lyall et al., 2015). However, despite increasing use of interdisciplinary pedagogical methods in higher education, the highly disciplinary structure of HE in the UK makes the formalisation of multidisciplinary and interdisciplinary degree courses problematic (Squires, 1992). This reflects a more general philosophy that higher levels of learning require greater levels of specialisation. Although joint honours programmes are offered in many universities, they are rarely fully multidisciplinary and are generally focused within similar subject areas (Pigden & Moore, 2018). Moreover, interdisciplinary single honours courses present challenges to the organisational structure of most UK universities (Nissani, 1997), and can be troublesome to implement and manage (Gantogtokh & Quinlan, 2017).

The high level of specialisation seen in UK universities also affects students' subject choices in further education, with students encouraged to tailor their post-16 subject choices towards the subjects most likely to secure them a place at university (Vidal Rodeiro, 2019). This further reduces the likelihood of students choosing combinations of subjects from different disciplines in FE, with the majority of combinations being within the same knowledge area and few students choosing both creative arts and STEM subjects (Vidal Rodeiro, 2019). This tendency towards mono-specialisation at FE level is likely to have a significant bearing on students future career trajectories, as subject choice of A level (Bibby et al., 2014), and the choice of whether to study A Levels or more vocational FE qualifications such as BTECs and NVQs (Patrignani et al., 2017), have both been shown to have a significant impact on future employment outcomes.

Consequently, there are growing calls for better integration of the arts and sciences in schools, colleges and universities, under the banner of STEAM (STEM+ Arts) learning (see Bequette & Bequette, 2012; Land, 2013; McAuliffe, 2016; Skorton & Bear, 2018). Drawing on policy discourse of the need for a 'STEM pipeline' (Colucci-Gray et al., 2019), STEAM advocates argue that arts based pedagogies can not only compliment and improve STEM learning (Root-Bernstein, 2015), but that, considering the growth of the creative industries in recent years, arts education should be viewed as similarly vital to securing the skills needed for the modern economy (Neelands et al., 2015; Cultural Learning Alliance, 2017). Here, both multidisciplinary and interdisciplinary approaches to combining creative arts and STEM learning have been championed, with research suggesting that STEAM education improves students interpersonal skills, develops collaboration capabilities and challenges the formation of strict disciplinary identities that can lead to an 'us vs them' professional mentality (Ghanbari, 2015; Sochacka et al., 2016).

However, while much has been written about the training and career pathways of creative arts students and STEM students, far less attention has been paid to those who have received an interdisciplinary or multidisciplinary education. Specifically, there remains little evidence to date surrounding the employment outcomes for those who have studied a STEAM curriculum and the extent to which these 'fused individuals' or 'trans-specialists' are entering work in the creative industries.

2.2.4. Graduate outcomes and the creative industries

Official UK statistics consistently show that university graduates who have completed a degree in a STEM subject are generally more likely to be in employment and to earn more than those who have studied creative arts subjects (DfE, 2019). However, with the growing economic and policy importance of the creative industries, there is a burgeoning body of work which examines employment outcomes specifically for those UK graduates entering the creative industries. Here we find that the majority of creative arts graduates go on to work in the creative economy and that creative arts graduates are vastly over represented in creative sectors, when compared to the general graduate population (Bloom, 2020). While few studies have assessed graduate outcomes in the creative industries for those with a broad background in STEM, some studies have examined the link between creative industries employment and certain STEM subjects. For example, Bloom (2020) finds that graduates from subjects such as computing and engineering earn more than creative arts graduates, even within the creative industries. This could be at least partially explained by Comunian et al.'s (2015) findings that Digital Technology graduates are more likely to work in certain subsectors of the creative industries and are subsequently likely to have a higher overall salary than more traditional arts graduates. Faggian et al. (2013) find a similar disparity in earnings between 'creative arts and design' graduates and 'creative media' graduates and additionally find that employed 'creative arts and design' graduates are less likely to be in full time employment than 'creative media' graduates. These studies are important in demonstrating a clear link between both creative and technological qualifications and employment in the creative industries in a UK context. However, they also demonstrate a consistent disparity between creative arts and STEM graduate outcomes. While this body of work is important for understanding the relationship between subject choice in HE and work in the creative industries, it does not address the situation for graduates who might fall into both groups – i.e. those with a mixture of creative arts and STEM qualifications, either as a consequence of joint honours or interdisciplinary degrees, or by studying a mix of subjects at or between FE and HE levels.

There has been some examination of graduate outcomes more generally for those who have studied combined degrees. Pigden and Moore (2018) specifically examine UK graduate outcomes for those who studied a joint honours degree. They find that students who had completed a joint honours degree were less likely to be in high skilled employment six months after graduation. Similarly Walker and Zhu (2011) find the average UK 'graduate premium' – i.e. additional earnings attributed to gaining a degree qualification – is lower for those who studied a combined subject, than for those studying STEM, or 'Law, Economics and Management' subjects. However, they find that those who study a combined subject have a higher 'graduate premium' than those studying 'Social Science, Arts and Humanities subjects'. This suggests that the addition of STEM training to Arts and Humanities training may improve employment outcomes. There is also evidence to suggest that the addition of creative arts training to STEM qualifications develops capabilities that are highly sought after in the jobs market. In the context of US higher education, Pitt and Tepper (2012) find that taking a double major in arts and sciences leads students from American universities to think more creatively and be more intellectually curious than their single subject counter parts. As recent survey data suggests that creative problem solving is one of highest prioritised skills for employers across the globe (Van Nuys, 2020), while joint honours courses may be regarded less favourably than single honours by employers, the skills arising from these types of degrees are still highly sought after.

2.2.5. Literature summary and paper aim

This review of extant literature indicates that there is evidence of a demand for fused individuals by creative industries employers. It has been theorised that this demand exists because the creative industries are increasingly reliant on highly specialised creative arts and STEM talent, and consequently, they are increasingly requiring fused 'trans-specialists' to act as boundary spanners and facilitate interdisciplinary teamwork. These boundary spanner skills can be gained through either *multidisciplinary* STEAM education, which gives students the languages and understanding of different disciplines needed to facilitate communication between diverse mono-specialists, or *interdisciplinary* STEAM education, which gives students the ability to synthesise ideas from different disciplines and facilitate the integration of mono-specialist knowledge. However, extant investigations of multidisciplinary and interdisciplinary provision in the context of UK higher education suggest that there is little opportunity for individuals to acquire these fused skills at higher levels of learning.

While there is a burgeoning body of research examining the link between HE and work in the creative industries, there is yet to be a comprehensive examination of the relationship between multidisciplinary and interdisciplinary STEAM education and creative industries employment. Moreover, there is yet to be work which considers both FE and HE qualifications in relation to graduate outcomes in this context. This paper addresses this gap by mapping the prevalence of skills fusion in the UK graduate population and assessing the likelihood of these graduates becoming employed in the creative industries.

2.3. Data and methods

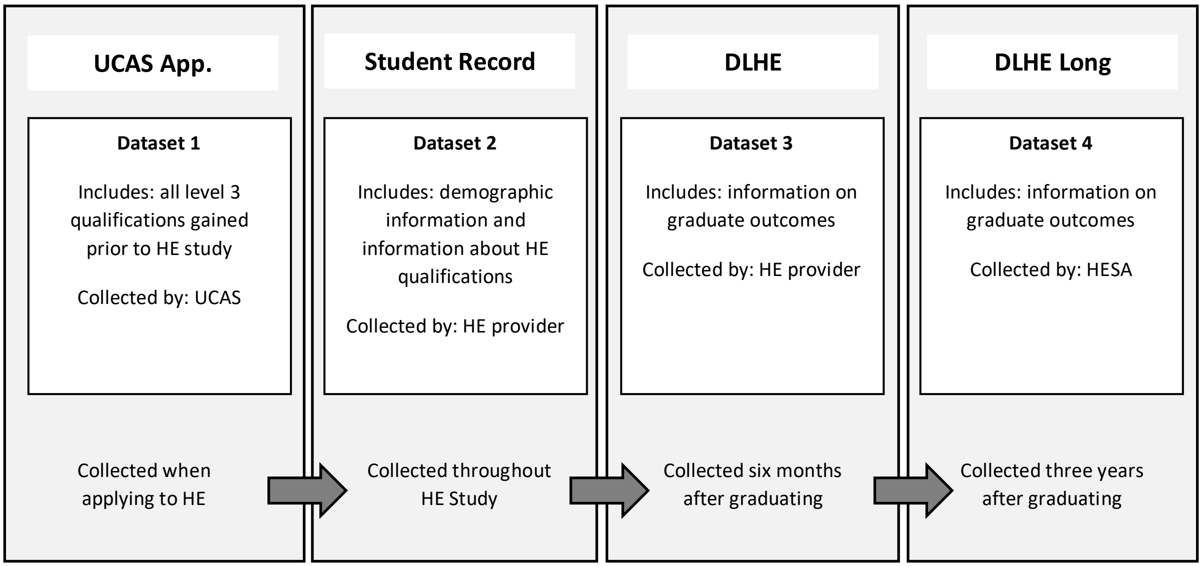
2.3.1. Data description

The paper combines four datasets from the Universities and Colleges Admissions Service (UCAS) and the Higher Education Statistics Agency (HESA) (see Figure 2 below). The first dataset used is provided by UCAS and details all UCAS tariff qualifications held by individuals who applied to university through the UCAS system[9]. It is from this dataset that it is possible to ascertain the disciplinary mix of a student's educational qualifications prior to HE study, which is both a novel and important factor in assessing skills fusion. Linked to this data is the Student Record, which consolidates data from individual Higher Education Providers for all students studying in HE. The Student Record includes demographic information for each student and details the course they are currently enrolled on or have recently finished. The third dataset used is the Destination of Leavers from Higher Education (DLHE) survey. This survey was distributed to all HE graduates six months after completing their course and was administered via each HE Provider. The survey records graduates' employment status on the snapshot date, and details of their current activities. This includes information about the industry and occupations employed graduates were working in at the time of the survey, recorded using SIC07 and SOC02 classification codes. The final dataset used is the DLHE Longitudinal Survey (DLHE Long). This survey was administered directly by HESA, and was distributed either by telephone, post or email, to all graduates for whom HESA have contact information (see IFF, 2017 for details). It collects similar

[9] Note, the data includes only UCAS tariff qualifications, such as A levels, BTECs, NVQs, Scottish Highers, Music grades 6-8 etc. See UCAS (2018) for full qualification list.

information to the DLHE but is conducted roughly three and a half years after graduation (henceforth referred to as three years) and thus offers opportunity to explore longer term graduate destinations. Each individual in the Student Record is given a unique ID by HESA, which can then be used to link individual level data across the four datasets. By linking these datasets it is possible to ascertain the subjects of each graduate's qualifications prior to HE study, the subject of their degree at HE level and their employment outcomes both six months and three years after graduation.

Figure 2 – Data description



The data used for this study is the linked 2012/13 dataset, which details all UK and EU higher education leavers who graduated from a UK university with an undergraduate or equivalent degree in that academic year. The 2012/13 dataset is the most recent dataset which includes graduate destinations three years after graduation, as the 2012/13 cohort was the last to complete the DLHE Long survey before it was replaced by the Graduate Outcomes survey, which is conducted only one year after graduation.

Several exclusion steps were initiated to produce the final dataset for analysis. Firstly, the data was reduced to include only those who were born in or after 1988 to mitigate the chance for additional training or work experience to influence results. This resulted in a universe of 322,520 students who had graduated from HE in the year 2012/13 with an undergraduate degree or equivalent, and who were roughly under 25 years old at the time of graduation. From this, any student who did not respond to the DLHE Long was also excluded, as this data was necessary to determine employment outcomes. As HESA provide a weighting for all student records pertaining to the DLHE Long, which takes into account 15 different profiling variables including those relating to subject, university, gender, socioeconomic background etc, this sample can be considered highly representative of the overall graduate population (see IFF, 2017). However, not all those who responded to the DLHE Long had available data pertaining to their pre-HE qualifications. This would be the case for anyone who did not enter university through the UCAS system, or anyone who did not have at least one UCAS recognised qualification (see UCAS, 2018 for qualification list), for example those with non-UK qualifications. Therefore those individuals who did not have at least one UCAS recognised qualification were also removed from the sample. While this final step may introduce some bias to the dataset, the paper's focus is on those who have undertaken traditional routes through the UK education system and therefore the majority of those individuals would have at least some UCAS relevant qualifications and would be included in the dataset. Consequently, the final dataset can be assumed to be highly representative of the group under investigation.

The steps outlined above resulted in a final dataset of 48,580 cases (with a weighted *n* of 48,760), which represents 15% of the potential universe of eligible students, and 89% of all DLHE Long respondents (see Table 4 below).

Table 4 – Sample size

Population	Unweighted *n*	% Base
First degree graduates born in or before 1988 (base universe)	322,520	100%
Has UCAS recognised qualifications	253,810	79%
DLHE Long respondents	54,635	17%
DLHE Long respondents with UCAS recognised qualifications (final sample)	48,580	15%

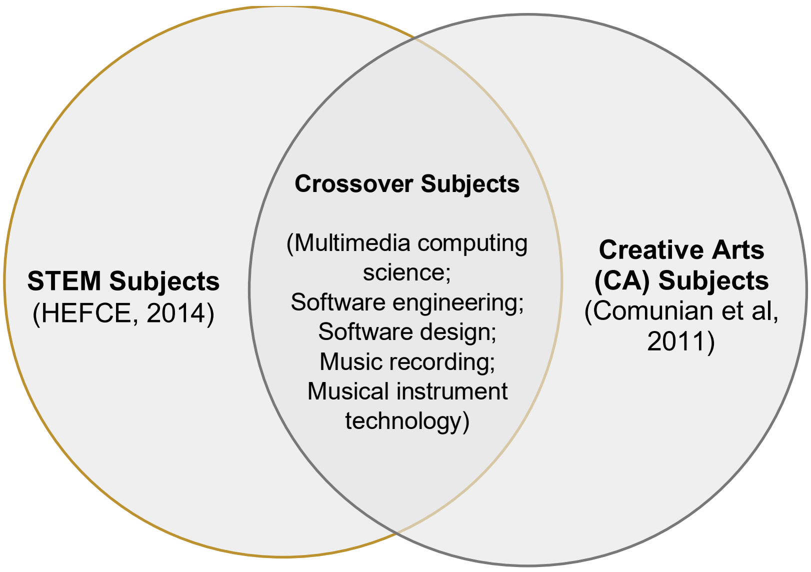
2.3.2. Measuring fusion

Fused graduates

This paper defines skills fusion as *the combination of information and proficiencies (skills) arising from different methods of advancing knowledge (arts and sciences), that are embedded within an individual, group or organisation and embodied through action*. Consequently, it operationalises fusion within individuals in relation to a combination of creative arts and STEM educational qualifications.

In order to assess Fusion, each HE qualification subject and each pre-HE qualification subject was assigned a category: Creative Arts (CA), STEM, or Other, plus a small 'Crossover' category (see Figure 3). For all HE qualifications, subject categorisation was based on the 4 digit Joint Academic Coding System (JACS) assigned to each course by HESA. CA subjects were defined following Comunian et al.'s (2011) categorisation of 'bohemian' university subjects, which correlate with the major categories of the DCMS definition of Creative Occupations (DCMS, 2016). Categorisation of STEM subjects follows the Higher Education Funding Council's definition of STEM (HEFCE, 2014). As five JACS codes appear in both definitions, these subjects have been categorised as 'Crossover' subjects. All other subject codes were categorised as Other.

Figure 3 – Definitions of STEM and Creative Arts



For pre-HE qualifications, subjects were not assigned a JACS code in the original data and were instead given a subject title by each exam board. Therefore, these 964 subjects were manually matched against JACS definitions based on similarity of name and were then allocated a JACS code to be used in categorisation. However, the definitions of CA and STEM subjects adopted by this paper had been originally operationalised using the JACS 2 coding system (Comunian et al., 2011; HEFCE, 2014). As the HESA data used in this study coded subjects according to an updated version of this system – JACS 3 – a final step was needed to convert all definitional subject codes into JACS 3, so that each subject code in the data could be accurately assigned a category[10]. This was done using mapping documents provided by HESA.

This study designates any person with at least one qualification in a STEM subject **and** one qualification in a CA subject (multidisciplinary skills) **or** at least one qualification in a Crossover subject (interdisciplinary skills) as being Fused. Any student with at least one qualification in a CA subject, but no qualifications in STEM or Crossover subjects were classified as CA Only[11]. Similarly those with at least one STEM qualification and no CA or Crossover qualifications were designated STEM Only. Those with no qualifications in CA, STEM or Crossover subjects were classified as Other.

Learning hours

The above method produces a metric for fusion which can be used to determine if any amount of learning at pre-HE or HE level in CA and STEM subjects influences the likelihood of working in the creative industries. However, it is also of interest to consider the extent to which greater amounts of learning in these areas affects this relationship. A scaler metric of fusion was therefore developed in order to be able to test the impact of fused learning in a more nuanced manner.

As this study assesses a range of different types of qualifications, from one year part time courses to three year undergraduate degrees, it is not possible to construct a scalar metric based only on number of qualifications in a given subject. Instead, each qualification type was assigned a number of learning hours (LH), which is the number of hours of study each course requires for completion. This was based on official requirements from awarding bodies described in The Register of Regulated Qualifications (Ofqual, 2018) and guidance documents from UCAS (UCAS, 2017, 2018).

[10] It may be of interest to note that as the HEFCE definition of STEM includes all subject codes within the Technology subject area, the subjects ‘Music recording’ and ‘Musical instrument technology’ fall within the STEM definition when using the JACS 2 coding system. Under the JACS 3 coding system, additional subject codes have been added for similar subjects such as ‘Music technology & industry’, ‘Sound design/commercial recording’ and ‘Creative music technology’. However, these new subjects have been categorised under the Creative Arts and Design subject area of the JACS hierarchy, as opposed to the Technology subject area. Therefore, when using the JACS 3 coding system these subjects would not fall under the HEFCE definition of STEM. In following the directives of the HEFCE definition of STEM, this paper has not designated these subjects as ‘Crossover’ subjects, despite their similarity to ‘Music recording’ and ‘Musical instrument technology’.

[11] It is important to note, that this group may have additional qualifications in a subject other than CA, but the term ‘only’ here refers to their lack of qualifications in a STEM or Crossover subject. The same approach applies to the STEM Only group.

To produce the scalar metric for fusion, subject categorisation was combined with LH to produce a Fused LH metric which includes any LHs in a Crossover subject, or any matched LHs in CA and STEM subjects[12].

2.3.3. Analysis

Analysis was conducted in three phases. Firstly, descriptive statistics were produced to indicate the number of STEM Only, CA Only and Fused graduates in the graduate population. Secondly, descriptive statistics were produced using the DLHE Long responses. This area of analysis included the main activity of graduates on the snapshot day, and the representation of graduates across the economy. Finally, probit regression was conducted to examine how a graduate's skillset affects their likelihood of entering the creative industries, when controlling for gender, socioeconomic class[13], degree class and university type. Analysis considered employment in the creative industries and employment in creative occupations based on DCMS definitions (DCMS, 2016). Following Higgs et al. (2008), the paper also considered the 'creative trident' which comprises of Specialist roles – creative occupations in the creative industries, Embedded roles – creative occupations outside the creative industries, and Support roles – non-creative occupations within the creative industries. The three of these groups together form the Creative Economy.

All analysis was conducted using the weighting methodology assigned to the data by HESA (see IFF, 2017). In accordance with HESA's standard rounding methodology (see HESA, 2019), all counts have been rounded in reporting with counts below 5, or percentages of groups fewer than 20, being suppressed. As such, some tables may not sum accurately.

[12] Values for this variable are produced by determining equal time spent studying Creative Arts and STEM subjects for each case. E.g. if Creative Arts LH = 10 and STEM LH = 10, then Fused LH = 20. Whereas, if Creative Arts LH = 10 and STEM LH = 5, then only 10 hours have been spent undertaking equivalent study of Creative Arts and STEM subjects, therefore Fused LH = 10 (with 5 extra Creative Arts subject learning hours).
[13] This variable uses the NS-SEC classification (see ONS, 2019). As the sample includes only students who were under the age of 21 at the time of this variable being recorded, classification is made on the occupation of the students' highest earning parent or guardian.

2.4. Findings

2.4.1. Fusion across the population

Table 5 below shows how many graduates have STEM Only, Creative Arts (CA) Only or Fused skills at pre-HE and HE levels. It shows that just under a quarter (24.3%) of 2012/13 graduates had a Fused skillset when considering both their pre-HE and HE qualifications.

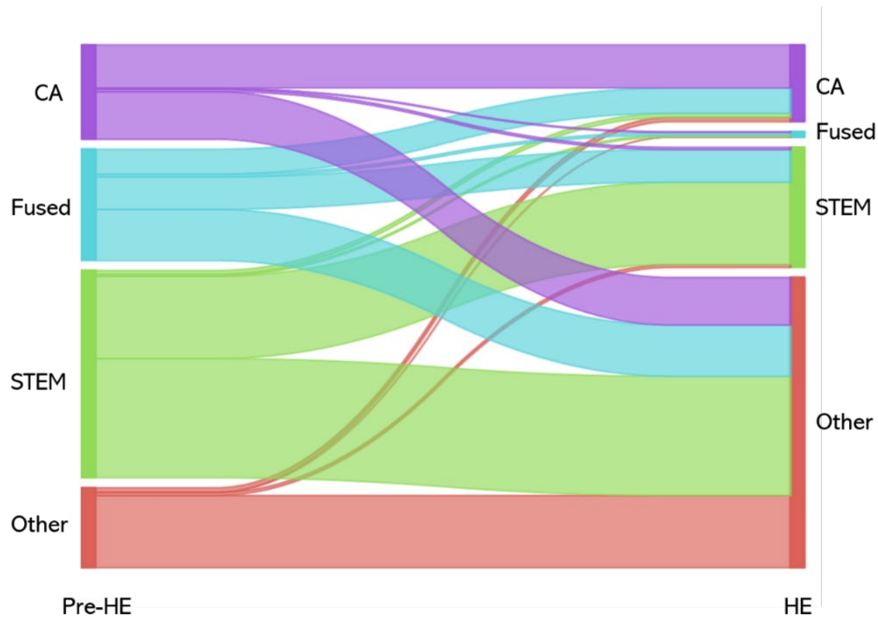
Table 5 – Fusion across levels

	Pre-HE	HE	Combined Skillset
STEM Only	41.3%	23.4%	40.7%
CA Only	19.7%	16.2%	20.0%
Fused	22.4%	1.1%	24.3%
Other	16.6%	59.3%	15.0%
Total	100.0%	100.0%	100.0%

Of particular interest is that whilst 22.4% of graduates are Fused at the pre-HE level, only 1.1% of graduates show evidence of fusion at HE level. Moreover, only 0.2% of graduates have a joint honours degree comprising of separate CA and STEM components. This confirms that higher education acts as a bottleneck for fusion and indicates the extent to which it restricts opportunities to undertake joint learning in both CA and STEM subjects. When we look to Figure 4 we can see that the majority of graduates have at least some qualifications in STEM and/or CA at pre-HE level (83.7%), but a minority of graduates (24.4%) go on to gain HE qualifications in these subject areas. This indicates there is an interest in studying subjects relevant for creative industries work when students are given the option to choose multiple subjects, but less of an interest when choosing a single degree course.

We also see the path dependent nature of the UK education system playing out, with very few students who were CA Only at pre-HE level going on to study STEM degrees (2.6%) and very few students who were STEM Only at pre-HE Level going on to study a CA degree (1.9%). Having Fused skills at pre-HE level however appears to give students more options, and we see a far more even split, with 29.2% of graduates who were Fused at pre-HE level going on to study STEM and 22.5% going on to study CA. Moreover, of those who are Fused at HE level (taking either a joint honours degree in a STEM and CA subject, or taking a degree in a Crossover subject), 44.9% of them had Fused skills at pre-HE levels. This implies that if Fused skills are important to the creative industries, then promoting fused learning at pre-HE level could contribute to the uptake of Fused learning at the HE level. Moreover, 54% of students who were fused at pre-HE level went on to study a creative industries relevant subject (e.g. CA, STEM or Crossover subjects) at HE level, compared to 49.4% of those who had previously only studied CA, 42.5% of those who had previously only studied STEM and just 9.8% of those with no CA or STEM pre-HE qualifications.

Figure 4 – Movement of graduates from pre-HE to HE skills groups



2.4.2. Graduate destinations

Once the distribution of fusion across the population had been mapped, analysis turned to graduate destinations. In the remaining analysis, each graduate was classified as Fused, CA Only, STEM Only or Other based on their overall skillset – i.e. the combination of both their pre-HE and HE qualifications. Table 6 shows some disparity in the major destinations of graduate groups six months after graduation, with those with a CA Only skillset more likely to be in employment than those with a STEM Only skillset, and those with a STEM Only skillset more likely to be in further study. However, three years on we see roughly similar outcomes across graduate groups.

Table 6 – Graduates' main activity by skillset

	STEM Only Skillset	CA Only Skillset	Fused Skillset	Other Skillset	All graduates
Six months after graduation					
Employed[14]	70.2%	78.0%	73.8%	72.2%	73.0%
Unemployed	6.8%	7.4%	7.3%	6.5%	7.0%
Further Study	19.9%	11.7%	15.8%	18.1%	17.0%
Other[15]	3.0%	2.9%	3.0%	3.2%	3.0%
Three years after graduation					
Employed	85.0%	87.6%	86.5%	89.0%	86.5%
Unemployed	1.8%	2.2%	1.9%	2.4%	2.0%
Further Study	11.2%	6.0%	8.8%	5.8%	8.7%
Other	2.0%	4.2%	2.7%	2.8%	2.7%

By three years after graduation, we do however see disparity in graduate employment across the creative industries. Table 7 below shows the proportion of differently skilled employees that make up the graduate workforce in the subsectors of the creative industries. Previous studies which focused solely on degree level qualifications have found that the majority of graduates employed in the creative industries have neither a CA or STEM degree (Comunian et al., 2014, 2015). However, when we consider pre-HE as well as degree level qualifications, we get a different picture. In this study we find that 91.3% of creative industries workers have at least some training in a CA or STEM subject (i.e. the sum of STEM Only, CA Only and Fused Skillsets in Table 7), compared to 83.5% of workers in other industry sectors. These results imply that the contribution of STEM and CA skills to creative industries work may have been underestimated in previous studies. Moreover, Fused graduates are found to be the biggest group in creative industries employment, meaning that the majority of those with STEM skills working in the creative industries also have some CA skills and vice versa. Not only are Fused graduates the biggest group, but they are also overrepresented when compared to the general population. Whilst Fused graduates make up 24.3% of all graduates in employment, they make up 33.3% of those working in the creative industries.

[14] including self-employed, freelance, voluntary work or other unpaid work

[15] This includes those who recorded their main activity on the survey snapshot date as being on holiday/traveling, sick, being a homemaker/carer, on parental leave, retired, developing a portfolio, or 'other'.

We do however find some substantial differences in skillsets across the different creative industries subsectors. It is perhaps unsurprising that architecture has the highest proportion of fused skilled graduates (65%), as architecture courses tend to draw on both engineering and artistic domains. However, it is interesting to note that around a third of the graduate workforce in IT, software and computer services have a fused skillset, indicating that creativity is a vital component to work in this area. It is also of interest to note that the subsectors with the lowest proportion of fused skilled graduates (Advertising and marketing, Publishing, and Museums, galleries and libraries) also have the highest proportion of 'other' skillsets in their workforce, suggesting that these industries are less reliant on both creative arts and STEM skills.

Table 7 – Skillsets in creative industries three years after graduation

Industry Sector	STEM Only Skillset	CA Only Skillset	Fused Skillset	Other Skillset	Total
Advertising and marketing	26.2%	34.2%	25.2%	14.4%	100%
Architecture	10.3%	21.2%	64.9%	3.6%	100%
Design: product, graphic and fashion design	6.6%	49.2%	41.0%	3.2%	100%
Film, TV, video, radio and photography	13.3%	44.6%	35.6%	6.4%	100%
IT, software and computer services	49.7%	11.2%	33.0%	6.1%	100%
Publishing	20.7%	36.5%	25.7%	17.2%	100%
Museums, galleries and libraries	19.9%	37.5%	29.5%	13.2%	100%
Music, performing and visual arts	6.4%	52.8%	37.4%	3.3%	100%
All Creative Industries*	24.9%	33.1%	33.3%	8.7%	100%
Other Industries	42.3%	18.2%	23.0%	16.5%	100%
All in employment (for reference)	*40.0%*	*20.2%*	*24.3%*	*15.4%*	*100%*

** This includes Crafts which have not been reported at subsector level due to low counts*

When looking at graduate destinations we find that a substantial proportion of those with fused skills are going on to work in the creative industries. Table 8 shows that 19.0% of

Fused graduates in employment are working in the creative industries three years after graduation. This compares to 22.6% of those with a CA Only skillset, 8.7% of those with a STEM Only skillset and 7.9% of those with an Other skillset. This means that around 1 in 5 fused graduates in our sample go on to work in creative sectors, indicating a strong match between fused skills and creative work.

Across subsectors, we see a high proportion of fused graduates finding work in the IT, software and computer services subsector, with 4.8% of fused graduates working in this area compared to only 4.4% of graduates with a STEM Only skillset and 3.6% of the general graduate population. We also find a high proportion of fused graduates finding work in Film, TV, video, radio and photography, with 3% of fused graduates finding work in this sector compared to 2.1% of the general graduate population.

Table 8 – Graduate destinations three years after graduation

Industry Sector	**STEM Only Skillset**	**CA Only Skillset**	**Fused Skillset**	**Other Skillset**	*All Skillsets (for reference)*
Advertising and marketing	1.9%	4.8%	2.9%	2.7%	*2.8%*
Architecture	0.2%	0.6%	1.6%	0.1%	*0.6%*
Design: product, graphic and fashion design	0.2%	2.4%	1.7%	0.2%	*1.0%*
Film, TV, video, radio and photography	0.7%	4.5%	3.0%	0.9%	*2.1%*
IT, software and computer services	4.4%	2.0%	4.8%	1.4%	*3.6%*
Publishing	0.8%	2.9%	1.7%	1.8%	*1.6%*
Museums, galleries and libraries	0.2%	0.9%	0.6%	0.4%	*0.5%*
Music, performing and visual arts	0.3%	4.4%	2.6%	0.4%	*1.7%*
All Creative Industries*	8.7%	22.6%	19.0%	7.9%	*13.9%*
Other Industries	91.3%	77.4%	81.0%	92.1%	*86.1%*
Total	100%	100%	100%	100%	*100%*

** This includes Crafts which have not been reported at subsector level due to low counts*

Table 9 shows that not only are Fused graduates overrepresented in the creative industries, but they are also overrepresented in creative occupations, again representing 33.3% of those employed in creative roles throughout the economy. We also see similar patterns across creative occupations to those we saw with creative industry sectors, in that a high proportion of those working in Design, Film, TV, video, radio and photography, and IT, software and computer services occupations have a fused skillset. However, we also find that whilst 37.4% of those working in Music, performing and visual arts *firms* have a fused skillset, a far larger proportion (42.4%) of those working in Music, performing and visual arts *occupations* have a fused skillset. This could potentially indicate the dominance of skills fusion in the more creative roles within this sector.

Indeed, when we look to the Creative Trident more broadly, we do find disparity in skillsets. It appears that STEM skills are mostly associated with support roles (non-creative jobs in the creative industries), whereas CA skills are most closely associated with embedded roles (creative roles outside the creative industries). Fused graduates are found to be the largest employed group in Specialist roles (creative occupations within the creative economy), indicating the importance of fused skills to the core of the creative industries.

Table 9 – Skillsets in creative occupations three years after graduation

Occupation Group	STEM Only Skillset	CA Only Skillset	Fused Skillset	Other Skillset	Total
Advertising and marketing	22.6%	37.9%	23.1%	16.4%	100%
Architecture	15.4%	15.1%	61.9%	7.6%	100%
Design: product, graphic and fashion design	1.0%	53.8%	43.7%	1.5%	100%
Film, TV, video, radio and photography	8.0%	47.6%	40.0%	4.4%	100%
IT, software and computer services	51.8%	7.6%	38.0%	2.6%	100%
Publishing	21.2%	38.8%	22.4%	17.6%	100%
Museums, galleries and libraries	18.5%	27.6%	26.4%	27.5%	100%
Music, performing and visual arts	2.3%	54.3%	42.4%	1.0%	100%
All Creative Occupations*	23.1%	34.2%	33.3%	9.3%	100%
Non-Creative Occupations	43.0%	17.7%	22.7%	16.5%	100%
Specialist (creative occupations in the creative industries)	20.4%	35.7%	36.1%	7.9%	100%
Embedded (creative occupations outside the creative industries)	26.9%	32.2%	29.4%	11.5%	100%
Support (non-creative occupations in the creative industries)	33.3%	28.1%	28.3%	10.3%	100%
Non-Creative Economy	43.8%	17.0%	22.3%	16.9%	100%
All in Employment (for reference)	*40.0%*	*20.2%*	*24.3%*	*15.4%*	*100%*

* *This includes Crafts which have not been reported at subsector level due to low counts*

2.4.3. Levels of Fusion

The previous results demonstrate that Fused graduates are overrepresented in the creative industries. In order to test if there is a statistically significant difference between graduates employed in the creative industries and those not employed in the creative industries in regards to skills fusion, an independent t-test was conducted to compare the average amount of fusion between these two groups using the Fused Learning Hours (LH) metric. Table 10 below shows the average fused LHs as a percentage of all learning for different industry and occupational groups. It is worth noting that no group had, on average, more than 10% of their learning hours as fused learning. This reflects the lower levels of fusion found at HE, which comprise a far greater proportion of a student's LHs than their pre-HE qualifications do.

Despite generally low levels of fusion across the groups, we do see that, for those working in the creative industries, an average of 7.6% of their learning was Fused, compared to 3.3% for those working outside the creative industries. This demonstrates that those working in the creative industries are significantly more fused than the general graduate population (where the average Fused Learning Hours as a percentage of all Learning Hours is 3.9%) and over twice as fused as those working outside the creative industries. Those working as Specialists (creative roles inside the creative industries) are the most fused group with 8.7% of their learning as fused, indicating further support for the argument that those working at the core of the creative industries are those with high levels of trans-specialisation.

Table 10 – Average Fused Learning Hours as a % of all Learning Hours

	Mean of those not in row category	Mean of those in row category	Mean difference	95% Confidence Interval of Difference	
				Lower	Upper
Creative Industries	3.3%	7.6%	4.2%	3.8%	4.6%
Creative Occupations	3.2%	7.7%	4.4%	4.0%	4.8%
Specialist	3.5%	8.7%	5.3%	4.9%	5.6%
Embedded	3.7%	6.3%	2.6%	2.2%	3.0%
Support	3.8%	5.6%	1.7%	1.3%	2.2%
Creative Economy	3.1%	7.2%	4.1%	3.7%	4.4%

Note: independent samples test significant for all statistics at p<0.05

2.4.4. Fusion as a predictor of creative industries employment

Finally, to test the extent to which being Fused impacts the likelihood of entering the creative industries, a probit regression was used, controlling for gender, socioeconomic class (based on parental occupation), degree class and university type. As age was already restricted in the sample, age was not included as a control variable. Table 11 shows the marginal effects of each regressor on the probability of graduates being employed in the creative industries (model 1), in a creative occupation (model 2), in a Specialist creative role (model 3), in an Embedded creative role (model 4), in a Support creative role (model 5) and in the Creative Economy (model 6).

The results show that fused graduates are roughly 12% more likely to be employed in the creative industries than those with no CA or STEM training. While those who have studied CA Only are 17% more likely to be in creative industries employment than those with no CA or STEM qualifications, there is no significant effect for having STEM Only training. We see similar effects on the likelihood of being employed in a creative occupation. However, here we additionally see that there is a small, but significant, negative effect for those with STEM Only qualifications. This suggests that not only does studying CA alongside STEM subjects increase the likelihood of being employed in creative work, but that those with STEM training only are actually less likely to be in creative occupations than those without any CA or STEM training at all. This finding is particularly interesting as it points to issues of self-selection bias. It may well be that the choice to take a CA subject, either at pre-HE or HE level, indicates a preference for creative work. However, we still find a difference in the likelihood of being employed in a creative occupation between the STEM Only and Other group, neither of whom received any CA training. This could suggest there is something about either the choice to study STEM subjects or the provision of STEM subjects which deters graduates from seeking creative work. Nevertheless, these results show that having a fused skillset significantly correlates with likelihood of employment in creative work when controlling for demographic and attainment characteristics.

Table 11 – Probit models of likelihood of entering creative work

	(1) Employed in the Creative Industries	(2) Employed in a Creative Occupation	(3) Employed in a Specialist Role	(4) Employed in an Embedded Role	(5) Employed in a Support Role	(6) Employed in the Creative Economy
Gender (ref. Male)						
Female	-0.069***	-0.060***	-0.046***	-0.009***	-0.019***	-0.080***
	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.005)
Socioeconomic classification (ref. Routine and manual occupations)						
Higher managerial, administrative and professional occupations	0.029***	0.035***	0.021***	0.012***	0.006*	0.041***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.006)
Intermediate occupations	0.007	0.004	0.006	-0.002	0.001	0.005
	(0.006)	(0.006)	(0.005)	(0.005)	(0.004)	(0.007)
Degree class (ref. Third Class honours)						
First class honours	0.090***	0.147***	0.085***	0.066***	0.010	0.157***
	(0.018)	(0.020)	(0.017)	(0.016)	(0.010)	(0.021)
Upper second class honours	0.056***	0.089***	0.045***	0.044***	0.010	0.103***
	(0.013)	(0.014)	(0.011)	(0.011)	(0.009)	(0.016)
Lower second class honours	0.013	0.033*	0.011	0.023*	0.003	0.036**
	(0.015)	(0.017)	(0.012)	(0.013)	(0.009)	(0.019)
University type (ref. Post-1992 Institution)						
Russell Group	0.029***	0.024***	0.023***	0.003	0.007**	0.032***
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.006)
Other Pre-1992 Institution	0.001	-0.003	-0.003	0.001	0.004	0.002
	(0.005)	(0.005)	(0.004)	(0.004)	(0.003)	(0.006)
Specialist Arts Institution	0.246***	0.241***	0.192***	0.029***	0.034***	0.310***
	(0.018)	(0.019)	(0.017)	(0.011)	(0.010)	(0.020)
Graduate skillset (ref. Other)						
STEM Only	0.001	-0.025***	-0.013**	-0.012**	0.013***	-0.013*
	(0.007)	(0.007)	(0.005)	(0.005)	(0.004)	(0.008)
CA Only	0.171***	0.174***	0.119***	0.057***	0.051***	0.218***
	(0.010)	(0.009)	(0.008)	(0.007)	(0.006)	(0.010)
Fused	0.117***	0.115***	0.084***	0.031***	0.031***	0.142***
	(0.008)	(0.008)	(0.007)	(0.006)	(0.005)	(0.009)
Observations	33,620	33,615	33,040	33,040	33,040	33,040
Pseudo R^2	0.069	0.075	0.088	0.025	0.016	0.071

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Considering this paper's thematic focus on specialisation, it is also worth noting that gaining a degree from a specialist arts institution is found to significantly increase the likelihood of being employed in the creative industries by around 25%, compared to graduating from a Post-1992 university. In contrast, graduating from a Russell Group institution only increases the likelihood by around 3%. This shows that there is indeed a strong link between creative specialisation and creative work, and demonstrates that despite profound changes to the role of arts schools in the higher education landscape over the last century (Banks & Oakley, 2016), they remain a vital engine in preparing young people for careers in the creative industries.

2.5. Discussion and conclusions

The aim of this paper was to map the prevalence of skills fusion in the UK graduate population and assess the likelihood of these graduates becoming employed in the creative industries. Whilst there has been work which assess employment outcomes for those studying creative arts subjects and those studying STEM subjects in higher education, there has been little research to date which explicitly considers graduates with both skillsets. Moreover, by taking into account both pre-HE and HE qualifications in determining a graduate's skillset, this paper has been able to create a robust metric for examining skills fusion in the graduate population and has been able to assess employment outcomes for these students in relation to work in the creative industries. This is an important step in beginning to unpack the findings of studies which have considered arts and STEM fusion at the firm level (Sapsed et al., 2013; Siepel et al., 2016, 2019) by indicating the extent to which 'fused firms' may be being supported by fused individuals who act as boundary spanners between creative arts and STEM specialists.

The paper finds that while fused individuals comprise around a quarter of the general graduate population, they make up around a third of the graduate population within the creative industries. This suggests that fused individuals are just as necessary to the sector as creative arts and STEM specialists. This is especially the case for sectors such as IT, software and computer services, and Film, TV, radio and photography, where collaboration and interdisciplinary project-based working are particularly common. Moreover, those graduates working in the creative industries are, on average, over twice as fused as those working outside the creative industries. This indicates that the innovation and growth found in creative industries firms, might be being driven by 'fused people' who can act as boundary spanners between creative arts and STEM specialists. This is supported by the finding that those working in creative jobs inside the creative industries are on average even more fused than those working in the creative industries in general, or those working in creative occupations. This suggests that fusion need not be the antithesis of specialisation, but is instead a way of fully capitalising on the benefits of specialisation, as fused trans-specialists can bridge the gap between creative arts and STEM disciplines.

Indeed, throughout this paper fused individuals have been referred to as 'trans-specialists', rather than the more commonly used specialists antonym 'generalists'. This is to reflect the fact that fused graduates may have high levels of skills in both creative arts and STEM subjects, or have high level skills which sit at the intersection of art and technology. This is particularly important as the need for high level knowledge of both CA and STEM subjects becomes increasingly necessary for creative work (Bakhshi et al., 2019). As the fourth industrial revolution comes to reorder the nature of work across almost all industrial sectors, it seems intuitively correct that those with advanced creative skills should also be versed in some elements of STEM learning and *vice versa*. The findings of this study go some way to supporting this argument.

However, findings show that the majority of skills fusion at HE level is taking place through interdisciplinary 'Crossover' subjects, rather than a multidisciplinary mix of separate creative arts and STEM components, with only 0.2% of graduates fitting into this group. Moreover, while the provision of interdisciplinary 'Crossover' courses is encouraging, the proportion of students taking these courses remains relatively low at less than 1%. It is clear from this that university education acts as a significant bottleneck to fusion. When given the option to choose multiple subjects at pre-HE level, 21.4% chose some combination of creative arts and STEM subjects, suggesting that there is interest in studying a diverse range of disciplines. So why is there not more uptake of joint honours courses at HE level? Pigden and Moore (2018) find a significant decline in the number of students graduating with a joint honours degree between 2011 and 2015. Their analysis suggests that this may be due to lower employment prospects, with students who completed a joint honours degree being less likely to be in high skilled employment six months after graduation. They also find however, that the gap in high skilled employment between joint and single honours students decreases in line with the number of joint honours courses available at a university. In other words, joint honours graduates from universities who provide more joint honours courses have better employment outcomes than joint honours graduates from universities with fewer join honours options. This implies that the "organisational, academic and cultural challenges" faced by joint honours students may be somewhat mitigated by increasing the number of joint honours courses offered by universities (Pigden & Moore, 2018, p.207).

2.5.1. Policy implications

There are clear policy implications arising from the findings of this study. Firstly, it is clear that the UK higher education system acts as a bottleneck to fusion. This is evident from the dearth of graduates who study both creative arts and STEM subjects at undergraduate level. As the creative industries are one of the fastest growing sectors of the UK economy, UK universities should be adequately preparing graduates with the skills required to work in this sector. It may well be the case that universities currently offer optional modules for students to broaden their skillset, but there is currently a lack of opportunity for students to evidence this in degree awards. This paper echoes recent recommendations to the European Parliament (Davies & Ward Dyer, 2019), in contending that continued growth of the creative industries requires increased opportunity to study a mix of creative arts and STEM subjects in higher education. Greater acceptance and promotion of joint honours degrees across disciplines would enable both the breadth of learning required for graduates to become fused at a higher level, and the ability for graduates to demonstrate this breadth of knowledge to potential employers.

Secondly, the results of this study support those advocating for the inclusion of creative arts in priority areas of skills development; the so called ‘STEAM’ agenda. The UK’s current industrial strategy puts great emphasis on STEM skills, including the specific need for STEM skills to support the growth of the creative industries (HM Government, 2017). Whilst the Creative Sector Deal acknowledges the need for a “combination of STEM and arts-based subjects” (HM Government, 2018, p.55), government support for the creative industries could be greatly improved by promoting fused learning through financial support and education policy targeted towards increasing uptake of multidisciplinary joint honours and interdisciplinary STEAM qualifications. As the valorisation of STEM skills increases, a recognition of the importance of combining STEM with creative arts skills is necessary to ensure the robust pipeline of adequately skilled individuals needed to support the future growth of this increasingly important sector.

Lastly, arts organisations, government, industry and educators should work to change the discourse around creative skills. The results of this study suggest that even a small amount of creative arts training can impact the likelihood of entering the creative industries. Previous studies have shown that the majority of arts graduates go on to work in the creative industries at some point in their career (Oakley, 2009; Frenette & Tepper, 2016; Bloom, 2020). The findings presented here suggest that even pre-HE qualifications in creative arts subjects significantly increase the likelihood of graduates entering the creative industries, as graduates who do not take a creative arts degree are more likely to enter the creative industries if they have some creative arts training at pre-HE level. As the uptake of creative arts subjects at A level have been in decline over the last five years (Ofqual, 2019), it is essential that the benefits of studying creative subjects in further education are made clear to students when they come to make decisions about further study and future employment.

2.5.2. Limitations and future directions

The main limitation of this study is that it relies solely on UCAS and HESA recognised qualifications. By reducing the sample to include only those who were born in or after 1988, the study design does reduce the number of years of work experience it would have been possible for any graduate to obtain before starting in higher education. However, it does not rule this out completely, and there was no way to capture work experience or less formal forms of training from the data used. This reduces the extent to which it is possible to fully understand individual level fusion, as on the job training is clearly a large part of skills development, and work experience a major aspect of hiring decisions. Moreover, this focus also limits analysis to those who have taken a 'traditional' educational pathway, and does not account for those who may have undertaken apprenticeships, or entered the job market without a degree[16]. The data used is however, perhaps the most accurate currently available means to assess individual level fusion as it relates to formal qualifications. As the creative industries attract a substantially high proportion of graduates, with 71% of the workforce holding a degree qualification compared to 44% in the wider UK economy (Giles et al., 2020), the study design is able to produce meaningful analysis relating to a large proportion of the creative industries population. A second limitation is that the data used for this paper only included graduates in a single cohort and that that cohort entered the job market a number of years ago. Further data could be considered for previous and subsequent cohorts, to

[16] For discussion of the focus on formal qualifications in creative industries policy discourse see (Guile, 2006; Banks & Hesmondhalgh, 2009)

ascertain if similar relationships are found in other time periods and to assess how fusion has changed over time.

3. Reassessing the Role of Common Knowledge in Processes of Knowledge Integration in the Visual Effects Industry

Abstract: Extant work has stressed that there is a 'trade off' for firms between the need for knowledge diversity to foster innovation, and the need for common knowledge to aid knowledge integration. This paper, however, departs from current theorisations by exploring whether innovation might occur not simply through finding an optimal midpoint between diversity and commonality, but through balancing different forms of knowledge, both common and diverse. The paper presents a novel theoretical framework of common/diverse knowledge which differentiates between syntactic, semantic and pragmatic common knowledge types, which operate at the component and system level. It then applies this framework to empirical investigation of knowledge practices in a highly innovative company in the visual effects industry. The findings of the paper demonstrate that it is possible to have commonality of some knowledge types and diversity of other knowledge types. Moreover, the paper demonstrates that the interplay between these different forms of common and diverse knowledge shape how knowledge is integrated and new knowledge is formed. In providing a theoretically driven taxonomy of different knowledge types, the paper provides a significant contribution to extant theory by expanding our conceptualisation of common/diverse knowledge and offering a novel framework through which the innovation and knowledge integration capabilities of a firm can be assessed.

Keywords: Common Knowledge; Innovation; Knowledge Integration; Visual Effects Industry; Diversity

3.1. Introduction

The integration of disparate knowledge is increasingly recognised as a key process through which firms innovate, and knowledge integration capabilities are widely regarded as essential for firm success (Kogut & Zander, 1992; Grant, 1996a; Tell, 2011). However, many scholars have highlighted that integrating knowledge is not a simple task and requires a certain amount of 'common knowledge', or shared understanding, to be successful (Grant, 1996b; Szulanski, 2002). As such, there is a general consensus that knowledge diversity is beneficial for innovation, but that knowledge commonality is necessary for integration (Cohen & Levinthal, 1990; Nooteboom, 1992; Carlile, 2004). This tension between the need for both common and diverse knowledge has been characterised as a 'trade-off' in much extant work, where commonality and diversity exist on a single spectrum and firms must find an appropriate balance between the two (Hoopes & Postrel, 1999; Nooteboom et al., 2007; Mengis et al., 2009; Hecker, 2011; Postrel, 2017).

This paper, however, departs from extant work by exploring whether innovation might occur not simply through finding an optimal midpoint between diversity and commonality, but through balancing different forms of knowledge, both common and diverse. In pursuing this line of argument, the paper investigates how an interplay of different forms of common and diverse knowledge shapes how new knowledge is formed in processes of knowledge integration. To do so, the paper first presents a novel theoretical framework for assessing different forms of common/diverse knowledge which differentiates between three different types of knowledge (syntactic, semantic and pragmatic) which operate at both the component (individual) and system (organisation) levels. The paper then uses this framework to explore knowledge integration processes in the visual effects industry through a singular in-depth case study of one of the UK's largest and most innovative visual effects companies. In doing so, the paper makes three significant contributions: firstly, by providing a theoretically driven taxonomy of different knowledge types, the paper significantly contributes to extant theory by expanding our conceptualisation of common knowledge. Secondly, the paper problematises the notion that commonality and diversity exist on a singular spectrum and introduces the idea that the interplay between different types of common/diverse knowledge shapes how new knowledge is formed and innovation achieved. Finally, the paper sheds light on innovation and knowledge integration processes within the visual effects industry, a high-growth and highly innovative sector which has received comparably little attention from an organisation studies perspective.

3.2. Literature review

3.2.1. Introduction to the literature

The combination and re-combination of ideas is central to the innovation process (Schumpeter, 1934). In order to innovate, firms re-combine existing knowledge in novel ways to create new knowledge (Hargadon, 2002). Thus, the breadth of a firm's knowledge base, alongside its capacity to integrate this knowledge, will have a direct impact on its innovation capabilities (Kogut & Zander, 1992). The Knowledge Bases literature suggests that firms, or networks of firms, are more innovative when they combine different knowledge bases, which consist of different approaches to learning and problem solving (Asheim, 2007; Grillitsch et al., 2016; Boschma, 2018). It has also been found that cross functional teams in which participants have a wide range of backgrounds and disciplinary knowledge, are likely to be more innovative than teams with a singular knowledge base, as heterogeneous working groups provide a greater breadth and scope of experience, expertise, and attitudes that can be drawn upon in the development of new products and services (Paulus, 2000; West, 2002).

However, the integration of differentiated knowledge is not a simple task, as knowledge can be ‘sticky’ and costly to transfer (von Hippel, 1994; Szulanski, 2002). Moreover, knowledge integration requires not just the transfer of knowledge between individuals, but the creation of new knowledge through combination (Tell, 2011); it is “both the shared knowledge of individuals and the combined knowledge that emerges from their interaction” (Okhuysen & Eisenhardt, 2002, p.317). Here knowledge integration can be seen as a form of ‘fusion’, where knowledge is embedded within an individual, group or organisation and is embodied through action. Accordingly, the potential gains of knowledge differentiation will be mediated by the ability of the firm to integrate diverse knowledge, and to use it collectively to produce new knowledge, goods and services (Demsetz, 1988; Grant, 1996b). As such, it has been argued that the primary role of the firm is to integrate the knowledge held in the organisation, aiding knowledge sharing between individuals, units or groups, and actively combining this knowledge to produce new knowledge (Grant, 1996b; Spender, 1996; Becker & Zirpoli, 2003).

It has also been argued that the efficiency of knowledge integration can be enhanced by increasing the elements of knowledge that are common to all organizational members (Kogut & Zander, 1992; Carlile, 2004). ‘Common knowledge’ improves communication through greater understanding of each other’s knowledge domains and aligns priorities, attitudes and approaches, towards a specified outcome (Grant, 1996a). However, knowledge cannot be both homogenous and heterogenous, and perfect common knowledge would eradicate the benefits of differentiated knowledge (Becker & Zirpoli, 2003; Hecker, 2011). As Dougherty (1992) put it, the “intrinsic harmony” of shared understanding can hamper learning and the creation of new combinations, as the opportunity for unanticipated combinations is reduced. Accordingly, Cohen and Levinthal (1990) describe an organisational ‘trade-off’ between the need for diverse knowledge to increase the repertoire of knowledge that can be drawn upon for innovation, and common knowledge to enable the successful integration of knowledge across knowledge domains.

This trade-off, or 'tension' (Erkelens et al., 2010), has been given some attention in the extant literature, with Mengis et al. (2009) finding that the benefits of common knowledge "levels off somewhere in-between not knowing enough and knowing too much" (p.10). Similarly, Nooteboom et al. find an inverted U shaped relationship between commonality/diversity of knowledge and innovation, with some knowledge diversity increasing levels of innovation, but too much diversity "decreasing understanding with a negative effect on innovation performance" (2007, p.1030). Further, both Hecker (2011) and Postrel (2002, 2017) develop production functions for assessing the conditions under which either common knowledge or differentiated knowledge are most beneficial for firm performance, finding that environmental conditions such as organisational structure and firm size create different 'optimal' levels. This is indicative of much work on the supposed 'trade-off' between common and diverse knowledge. Whilst authors may operationalise various aspects of knowledge, such as language, trust, motivations etc, extant work has largely viewed common knowledge as a homogenous phenomenon and treats its usefulness as scalar, i.e. a singular entity of which there can be 'more or less'. Whilst Carlile (2002, 2004) has suggested that different types of common knowledge are necessary to overcome different knowledge boundaries, and Grant (1996b) has suggested that different forms of common knowledge serve different functions, there is yet to be work which considers the *interplay* of *different types* of knowledge in finding the balance between commonality and diversity.

The remainder of this section reviews the literature on common knowledge, knowledge integration and knowledge diversity, to explicate the importance of both commonality and diversity of knowledge to a firm's innovation capabilities. In doing so, it also highlights a significant gap in our theoretical understanding of the interplay of different types of knowledge in knowledge integration processes.

3.2.2. Common Knowledge

Broadly speaking, common knowledge refers to any knowledge which is common to more than one member of an organisation, or "the intersection of their individual knowledge sets" (Grant, 1996b, p.115). With such a broad definition it is unsurprising that extant literature has used the concept to describe a number of different types of knowledge. In perhaps its simplest form, common knowledge has been equated to basic linguistic and arithmetic ability (Demsetz, 1988). Elsewhere, this has been extended to shared language or common codes of communication (Kogut & Zander, 1992; Nooteboom, 1992; Teece et al., 1997). Whereas others have incorporated shared meaning and understanding (Bechky, 2003), and shared cultural knowledge (Hecker, 2011).

The concept of common knowledge plays a pivotal role in the Knowledge Transfer, Absorptive Capacity, and Knowledge Integration literatures. While there is much overlap between these strands of research, their conceptualisation of common knowledge somewhat differs, in part due to whether knowledge is seen as a resource or an activity (Paulin & Suneson, 2012). In the Knowledge Transfer literature, common knowledge is seen as necessary for knowledge to pass smoothly from sender to receiver (Szulanski, 1996). Knowledge Transfer largely views knowledge as a resource that, once codified, can be passed between individuals (Tell, 2011). As such, definitions of common knowledge in this strand tend to focus on the shared language needed for communication, and the shared meaning needed for that communication to be successful. In the Absorptive Capacity literature, it is not just that language and meaning are necessary for knowledge transfer, but in order to successfully absorb new knowledge, firms must know both where to search for knowledge and how to apply it (Zahra & George, 2002). In this strand of research, common knowledge is linked to ‘prior related knowledge’, highlighting the path dependent nature of knowledge accumulation (Cohen & Levinthal, 1990). Thus, in the Absorptive Capacity literature, common knowledge includes not just the shared language and shared understanding needed for knowledge transfer, but also a level of knowledge overlap (Mowery et al., 1996). Consequently, in this strand of research, common knowledge is often closely linked to the relatedness of knowledge (Lane & Lubatkin, 1998).

The Knowledge Integration literature, however, takes a markedly more innovation focused stance. It is concerned not just with knowledge transfer – the passing of knowledge from A to B - or the absorptive capacity of a firm – how A acquires, assimilates and applies knowledge from B – but instead how new knowledge is created by integrating knowledge from multiple knowledge domains – A+B=C (Okhuysen & Eisenhardt, 2002; Berggren et al., 2011). As Newell et al. aptly put it, knowledge integration “does not simply involve the mechanistic pooling of the various ‘pieces’ [...]. Rather, the integration of knowledge depends on joint knowledge generation” (2004, p.45). Here knowledge is seen as an ‘ongoing collective process’, which emerges from social interaction (Huang & Newell, 2003). It is “something people do instead of have” (Erkelens et al., 2010, p.96). Thus, from an integration perspective, common knowledge might consist of common language, common meanings, common cultures, common world views, common ways of working as well as trans-specialist knowledge, or knowledge of others' knowledge domains. This paper takes a Knowledge Integration perspective, viewing common knowledge as any type of knowledge common to more than one individual that is utilised in producing new combined knowledge.

3.2.3. Knowledge Integration

Common knowledge can be thought of as a key mediating factor in the knowledge integration process. However, there are a range of other factors which have been shown to affect the success of knowledge integration. These factors can be broadly grouped in relation to characteristics of the knowledge to be integrated, characteristics of the relationships among individuals and among individuals and the firm, and characteristics of the task at hand (Erkelens et al., 2010; Tell, 2011; Jin & Kotlarsky, 2012). Table 12 below shows the range of factors which have been shown to affect the knowledge integration process.

Table 12 – Antecedents to knowledge integration

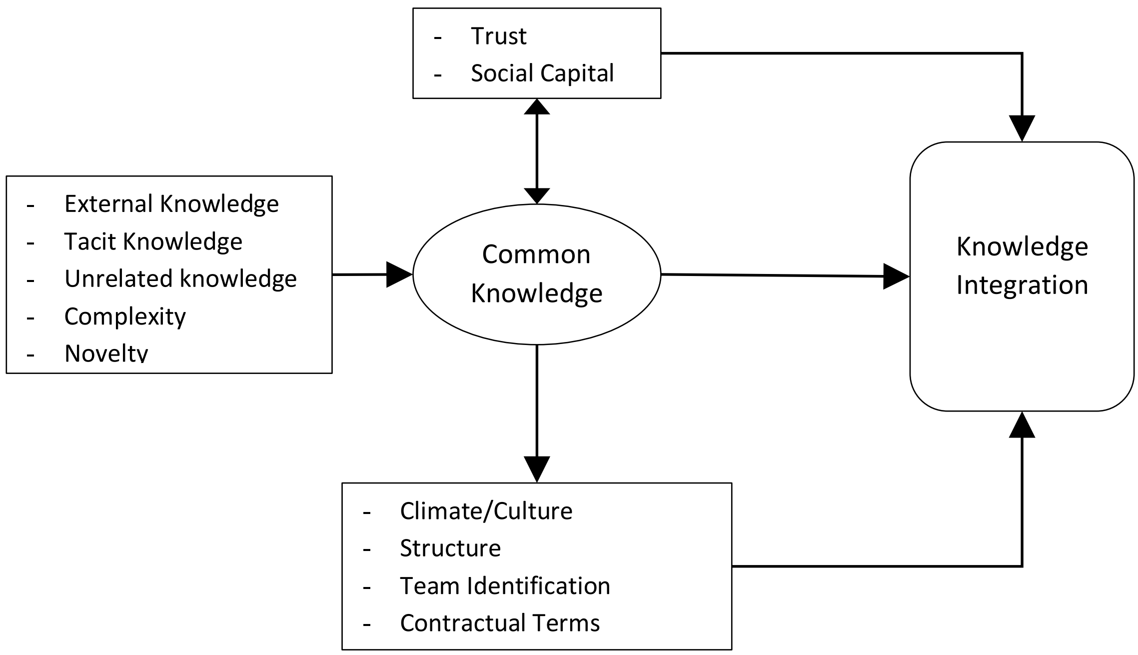
Knowledge characteristics		
Internal vs external	Whether the knowledge to be integrated has been generated inside or outside of the firm	(Grandori, 2001; Becker & Zirpoli, 2003; Dibiaggio, 2007; Ahuja & Sinclair, 2012)
Tacit vs explicit	Whether the knowledge to be integrated is explicit/codified – i.e. can be transferred through language, documents etc – or tacit – i.e. know-how type knowledge which is not easily expressed in words	(Grant, 1996b; Nonaka, 1994; Enberg et al., 2006; D'Adderio, 2001)
Related vs unrelated	The extent to which the knowledge to be integrated is related to current knowledge	(Breschi et al., 2003; Tanriverdi & Venkatraman, 2005)
Complement vs substitute	Whether the new knowledge is complimentary to existing knowledge, or replaces exiting knowledge	(Dibiaggio & Nasiriyar, 2009)
Relational characteristics		
Organisational culture/climate	The work environment or culture of the organisation, department or team	(Kogut & Zander, 1992; Argote et al., 2003; Woiceshyn & Daellenback, 2005; Collins & Smith,

		2006; Hung et al., 2008; Erkelens et al., 2010)
Structure (of team/project/organisation)	The relationship between members of a team/project/organisation in regards to power, hierarchy and communication flows	(Grant, 1996b; Huang & Newell, 2003; Hung et al., 2008; Ordanini et al., 2008; Tiwana, 2008; Ravasi & Verona, 2001; Bhandar, 2010; Erkelens et al., 2010)
Team/organisation identification	The extent to which members of a team/organisation feel a personal connection to that team – e.g. how their sense of identity is constructed as a team member	(Kogut & Zander, 1996; Ordanini et al., 2008; Willem et al., 2008; Grandori, 2001; Erkelens et al., 2010; Liu & Phillips, 2011; Ahuja & Sinclair, 2012)
Trust	The ability to trust other people's motivations, capabilities and actions	(Rauniar, 2005; Willem et al., 2008; Bhandar, 2010; Erkelens et al., 2010)
Social capital	A resource based on social and network relations that manifests through the enactment of norms	(Huang & Newell, 2003; Newell et al., 2004; Frost & Zhou, 2005; Bhandar et al., 2007; Bhandar, 2010; Zhang et al., 2020)
Interests and motivations of actors	The personal reasons members have to share knowledge	(Carlile, 2002, 2004; Rauniar, 2005; Enberg et al., 2006; Adenfelt & Maaninen-Olsson, 2007; Bhandar, 2010)
	Task Characteristics	
Contractual terms/ strategic objectives	The agreed upon outcomes of a given task or set of tasks	(Rauniar, 2005; Adenfelt & Maaninen-Olsson, 2007; Bhandar, 2010)
Complexity and decomposability	The extent to which the task requires multiple interwoven elements, or can be broken down into simpler component parts	(Grandori, 2001; Zollo & Winter, 2002; Becker & Zirpoli, 2003; Enberg et al., 2006; Schmickl & Kieser, 2008; Enberg et al., 2010; Ahuja & Sinclair, 2012; Thatcher et al., 2011)
Novelty and uncertainty	The extent to which the likely outcomes of the task are known or are knowable	(Carlile & Rebentisch, 2003; Woiceshyn & Daellenback, 2005; Stock & Tatikonda, 2008)
Task frequency and homogeneity	The extent to which the task reoccurs and the extent to which it differs from other tasks performed in the organisation	(Zollo & Winter, 2002; Enberg et al., 2006)

Source: adapted from Tell (2011) and Jin and Kotlarsky (2012), with substantial alterations and additions made by the author

For each of these factors, there is evidence of the influence of common knowledge, either as a product of that factor or as a prerequisite for that factor to lead to successful knowledge integration. Figure 5 (below) synthesises the findings from Table 12 (above) to demonstrate the role that common knowledge has been found to play in processes of knowledge integration. The figure depicts how common knowledge mediates the potential problems associated with integrating external, tacit, unrelated, complex and novel knowledge and how common knowledge helps to create organisational culture, formal structures and team identification. It also shows how trust and social capital both require common knowledge and create common knowledge and are essential antecedents to successful knowledge integration.

Figure 5 – Theoretical model of the role of common knowledge in processes of knowledge integration



3.2.4. Knowledge Diversity

In the majority of the extant literature, common knowledge is treated as faciliatory; increasing the effectiveness of knowledge integration by allowing employees to communicate their ideas more effectively, and to work together more productively (Demsetz, 1988; Grant, 1996a; Bechky, 2003; Huang & Newell, 2003; Carlile, 2004; Ness & Riese, 2015). However, a smaller body of work has considered common knowledge as a potential hindrance to innovation. Stark's work on the organisation as heterarchy (2011), discusses the positive implications of a diverse workforce, arguing that the dissonance that can occur as a result of differing knowledge domains can be constructive in moving ideas forward and creating new knowledge. He argues that it is not simply that an increase in diverse attitudes increases the likelihood of innovative combination, but that the dissonance produced by 'colliding and competing' discursive frames produces new knowledge through reflexive negotiation. It is the misalignment between "viewpoints, potential solutions, and perspectives held by individual team members [...which] facilitates experimentation with novel associations" (Tiwana & Mclean, 2005, p.20). Similarly, Nonaka and Toyama argue that new knowledge is created "through the synthesis of contradictions, instead of finding an optimal balance between contradictions" (2003, p.3). Moreover, Lester and Piore argue that it is the ambiguity that arises from these contradictions that "is the critical resource out of which new ideas emerge" (2009, p.54). Here then, it is argued that it is the miscommunication, misunderstanding or misalignment that results from a lack of common knowledge that produces novel combinations and drives innovation. Accordingly, studies have shown that greater innovation occurs when teams encompass a greater diversity of education type (Wiersema & Bantel, 1992) or employment discipline (Bantel & Jackson, 1989; Fay et al., 2006), that firms with a more diverse work force have a greater propensity towards innovation (Østergaard et al., 2011), and that firms which combine or 'fuse' different knowledge domains, such as arts and sciences, are more innovative than firms which rely on only one of these areas of knowledge (Sapsed et al., 2013; Siepel et al., 2016, 2019).

In summary, whilst common knowledge has been shown to be an integral facet of successful knowledge integration, a lack of common knowledge has also been shown to promote innovation through the creation of ambiguity and contradiction. However, extant work has largely viewed common knowledge as a singular entity of which there can be 'more or less' and is yet to fully explore the interplay of different types of knowledge in finding a balance between commonality and diversity. Therefore, this paper assesses how the interplay of common and diverse knowledge shapes the process of knowledge integration.

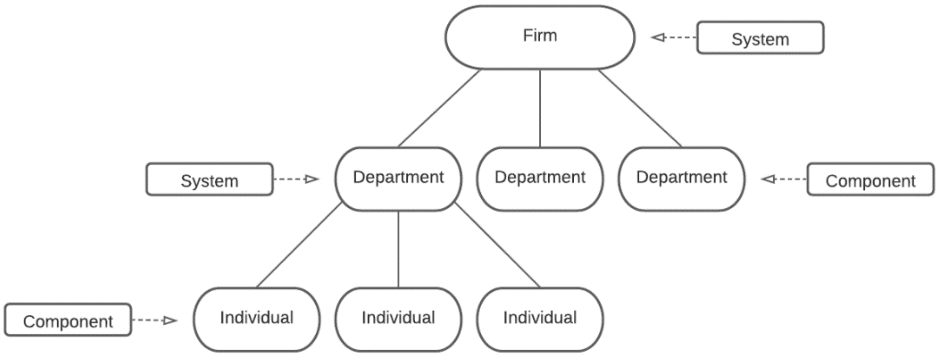
3.3. Theoretical framework

In examining the interplay of common and diverse knowledge in the knowledge integration process, this paper develops a framework adapted from Carlile's framework for knowledge transfer across boundaries (Carlile, 2002, 2004). Carlile identifies three increasingly complex knowledge boundaries: i) syntactic, ii) semantic and iii) pragmatic. He argues that at each of these knowledge boundaries, the processes used to transfer knowledge become increasingly complex. He distinguishes between the domain specific knowledge that exists either side of the boundary, and the common knowledge required for that boundary to be overcome, arguing that different forms of common knowledge are required to transfer, translate and transform knowledge between knowledge domains. Consequently, Carlile's framework for knowledge boundaries provides a useful tool for examining the interplay of different forms of common knowledge. However, in order to be fit for purpose, it must be adapted in two ways.

Firstly, Carlile's framework focuses on explanation of the knowledge boundary, with an intention to provide a heuristic to aid the formation of common knowledge. This paper adopts Carlile's concepts of *syntactic*, *semantic* and *pragmatic* boundaries, but applies them directly to knowledge itself. Thus: *Syntactic Common Knowledge* refers to a common syntax or mode of expressing knowledge, such as spoken language or written code. *Semantic Common Knowledge* refers to the meaning taken from syntax, what we understand when we read a written code, or hear a certain word, and is highly context specific. *Pragmatic Common Knowledge* refers to the values that affect how we receive knowledge and the actions we take on the basis of these values, in other words: shared values, motivations, priorities and goals.

The second way in which this paper's framework differs from Carlile is the theoretical distinction between *component* level common knowledge and *system* level common knowledge. Spender (1996) views the firm as a system of knowing, and argues for the importance of distinguishing between component and systemic knowledge. Similarly, Kogut and Zander argue that knowledge is 'held' both by individuals, and in the "organizing principles by which relationships among individuals, within and between groups, and among organizations are structured" (Kogut & Zander, 1992, p.384). As such, it is necessary to distinguish between the level of the individual or component - where knowledge may be common or differentiated - and the organisation or system - which by definition forms a common framework within which knowledge integration occurs. These units are, to a certain extent, flexible, in that a department might operate both at a system level in relation to the individuals within that department, and at the component level in relation to the wider firm (see Figure 6 below). The framework developed here will therefore distinguish between component (individual or department) and system (department or firm) level common knowledge, across each common knowledge type.

Figure 6 – Component and system levels



Accordingly, the paper presents six categories of common knowledge: i) common signs, ii) common codes, iii) common understanding, iv) common indexicality, v) common identity and vi) common culture. Table 13 describes the framework of these categories and examples of the forms of knowledge that each category may take.

Table 13 – A framework of common knowledge

Knowledge type		**Component**		**System**
Syntactic	**i)**	**Common signs**	**ii)**	**Common codes**
	-	Language	-	Software
	-	Terminology	-	Standard measures
	-	Jargon	-	Templates/pro forma
Semantic	**iii)**	**Common understanding**	**iv)**	**Common indexicality**
	-	Interpretation	-	Shared expectations
	-	Frames of reference	-	Agreed deliverables
	-	Thought worlds		
Pragmatic	**v)**	**Common identity**	**vi)**	**Common culture**
	-	Independent values	-	Collective values
	-	Independent priorities	-	Collective priorities
	-	Independent goals	-	Collective goals
	-	Motivations	-	Incentives

Common Signs and Common Codes

These two categories rely on syntactic common knowledge. At the component level (common signs) this category primarily represents language, including the use of jargon or specialist terminology. At the system level (common codes) this could represent firm or group level terminology, such as account codes, but could also incorporate formal inputs such as software use and standard measures. Literature on knowledge integration heavily stresses the need for common syntactic knowledge, in order for people to be able to communicate their ideas successfully (Mengis, 2007; Tell, 2011; Van de Ven & Zahra, 2017). If however, people do not have this syntactic common knowledge, then each party must explain their ideas in a language the other would understand. This could involve either changing the language used, or creating a boundary object, such as a drawing, prototype, or metaphor that is used as a “means of translation” (Star & Griesemer, 1989, p.393). Such boundary spanning activities do not just enable parties to speak to one another in the same language, but the process of rearticulation can itself stimulate new meanings (Bechky, 2003). Communicating in a different way requires abstract thinking which is productive in creative thought, as “encouraging people to move to more abstract problem characterizations will lead to more innovation” (Ward et al., 1999, p.198). Thus in overcoming syntactic misalignment, the rearticulation or explanation of an idea using a different language, or the questioning of a standard can stimulate new knowledge. Accordingly, the process of overcoming an absence of syntactic common knowledge may be more productive for innovation than straightforward communication between parties who already speak the same language.

Common Understanding and Common Indexicality

These two categories rely on semantic common knowledge; the meaning we take from syntax and/or the meaning we intend to evoke when using syntax. Meaning can be constructed at the component level (common understanding), based on prior experience, or at the system level (common indexicality) where syntax is interpreted in the context of the team or firm. As Nelson and Winter observe, “The internal language of communication in an organisation is never plain English: it is a dialect full of locally understood nouns [...] involving very localized meanings for "promptly", "slower", "too hot", and so on" (1982, p.102). Similarly, Postral (2017) talks of the co-ordination failure that can occur when two parties agree on the stated direction of a task, but have differing understandings of what this direction means. However, Dougherty (1992) argues that whilst an organisation should strive to reduce differences in understanding, differentiated 'thought worlds', or ways of interpreting information can create unique insights. Moreover, Brun et al. (2008) find that ambiguity, or "different interpretations of the same piece of information" (p.304), is a critical resource for new product development as it promotes novel combinations of ideas.

Common Identity and Common Culture

These two categories relate to pragmatic common knowledge, or shared values. At the system level (common culture), this can "usefully be viewed as a label for basic principles on how to behave in the organization" (Willem et al., 2008, p.p.371). However, Willem et al. (2008) assert that whilst one might adopt the values of the group, an individual may still hold personal beliefs (common identity) that could be at odds with those of the firm. Adenfelf (2007) find that at the component level, successful knowledge integration is influenced by the interests and motivations of the actors involved. At the system level, Enberg et al (2006) find that even when project goals set by an organisation are vague and undefined, the mere existence of such goals can strengthen team members willingness to integrate their specialised knowledge. However, Stark (2011) argues that difference in values, priorities and motivations are essential for innovation. Building on Boltanski and Thévenot's (2006 [1991]) work on the justification of worth, Stark (2011) argues that the dissonance that results from competing 'evaluative frames', or opinions on what constitutes 'worth', is necessary to produce novel combinations. Moreover, he argues that by keeping multiple values of worth 'at play' in an organisation, firms are better able to respond to dynamic market conditions.

By delineating these different forms of knowledge, we can see how it is possible to hold common knowledge in one of these areas but lack common knowledge in another. As there is a rationale for the benefits of both common and diverse knowledge in each of these categories, it appears fruitful to not only consider common or diverse knowledge within each category, but to consider the interplay between each category also.

3.3.1. Research question

The preceding sections have discussed the benefits of diverse knowledge for innovation, and the need for common knowledge to aid integration. This has been described as a trade-off in much of the extant literature and some work has been conducted to discover the 'optimal level' of common knowledge required to benefit firm performance. However, it has been suggested here that different types of knowledge may be common or diverse and that it is the interplay of different forms of knowledge that shape the knowledge integration process. The main question that this paper will address therefore is:

How does the interplay of different forms of common and diverse knowledge shape how new knowledge is formed in processes of knowledge integration?

3.4. Methodology

3.4.1. Research design

As knowledge integration processes involve multiple actors and are highly complex, understanding of these processes requires rich, qualitative data from multiple standpoints. Correspondingly, Tell (2011) calls for an in-depth case study approach to researching knowledge integration, that is able to gain insight into the situated, dynamic and complex mechanisms that underpin this process. The case study method is particularly effective in studying what Yin refers to as 'knowledge utilization', because it constitutes a phenomenon that appears to be "inseparable from its context" (Yin, 1981, p.99). Whilst the situated nature of case study research allows for greater contextualisation of research findings, that is not to say that generalisable claims may not be substantiated. An 'instrumental' approach to case study methodology (Stake, 1995) means that cases can be used to 'facilitate' understandings of wider practice (Baxter & Jack, 2008) and to build theory (Eisenhardt, 1989). A case study approach to examining the interplay of common and diverse knowledge therefore offers opportunity to gain a situated understanding of knowledge integration processes and to develop this understanding into theoretical propositions that may be more widely applied. In seeking to gain this situated knowledge, a single case design was deemed the most appropriate way to test, extend and develop theory. Moreover, it was decided that an embedded case study design (Yin, 2009), which took multiple projects within a single firm as the unit of analysis was the most effective way of researching the selected case. Because knowledge integration is a relatively amorphous concept, by focusing the investigation at the project level, it was possible to bound the study within project parameters thus enabling situated accounts of specific knowledge integration processes.

Case selection focused on finding an exemplar firm where knowledge integration between diverse knowledge domains was successfully leading to innovation. The rationale for case selection is further elaborated below.

3.4.2. Industry and case selection

The visual effects (VFX) industry was chosen as the context for this study for a variety of reasons. Firstly, the VFX industry employs highly specialised technical and creative experts and relies heavily on cross-functional teamwork (Seymour & Coyle, 2016). These teams are not just cross-functional, but interdisciplinary, typically encompassing employees from a wide variety of backgrounds, ranging from those who studied fine art to those with advanced physics degrees (Livingstone & Hope, 2011). Moreover, VFX firms can be seen an archetype of heterarchy, where diversity of skills, organizational principles and 'frames of action' are in constant flux (Spelthann & Haunschild, 2011). As such, the VFX industry is one in which diverse knowledge from multiple domains is incorporated into a single 'product' – the film – through constant interaction between diverse experts. Furthermore, as VFX work is distinctly creative in nature, innovation is a fundamental output of every project.

The VFX industry is representative of a tripartite shift in the dynamics of the film industry: increased reliance on digital technology (Pratt & Gornostaeva, 2009), vertical disintegration of the Hollywood studio system (Christopherson & Storper, 1986; Storper & Christopherson, 1987; Scott, 2005) and globalisation of film production (Curtin & Vanderhoef, 2015; Curtin, 2016). In this context, technological (e.g.: Harris, 1997) and policy (Christopherson & Clark, 2007; Hemels, 2017) innovations have enabled alternative economic geographies to emerge (Davis et al., 2009; Pratt & Gornostaeva, 2009; Chapain & Stachowiak, 2017). In recent years, creative clusters in Canada – Montreal, Toronto and Vancouver – and the UK – London – have supplanted Hollywood and California as engines of VFX production (McDonald, 2016). With big budget feature films now regularly allocating a majority of their costs to outsourced VFX services (McDonald, 2016), these clusters have become important economic drivers and centres of cinematic labour.

Specialist VFX firms provide contracted services as part of the audiovisual production supply chain. Typically, they do not own any of the intellectual property of the audiovisual product, but bid for tender or are commissioned to generate, augment or enhance specific shots and sequences to the specification of the product owner – the director, producer and/or studio. Often, multiple VFX firms will be contracted to simultaneously provide different services and/or work on different elements of an audiovisual product. Accordingly, clustered VFX firms find themselves balancing competitive and collaborative dimensions of market, product and geographic proximity, with the ability to innovate – both creatively and technologically – being a key source of differentiation and competitive advantage.

Within the VFX industry, the company Framestore was selected to be the focus of the study. Framestore was chosen as it is one of the top visual effects companies in the world, with a proven track record of innovation. The company has almost tripled its turnover in the last ten years to around £91m, making it the third largest visual effects company in the UK (FAME, 2021). It has won multiple Academy Awards and BAFTAs for its work on films such as The Golden Compass, Paddington and the Harry Potter series. Moreover, Framestore represents an ideal case for this research as they have a long-standing history of innovation, winning the BAFTA for innovation in 2000 for their work on Walking With Dinosaurs and developing ground-breaking visual effects techniques for films such as Gravity.

3.4.3. Case and project description

Framestore is based in London, with additional operations in Canada, the USA and India, employing around 2,500 staff globally, with around 1,000 staff in the UK. The company has three major divisions: film, advertising and immersive content. This paper focuses on three specific projects within the film division at the central London office.

The film division was chosen as the case site as projects in this division are more extensive in regard to time and labour than the advertising division and require more sustained integration of creative and technological knowledges. The three specific projects chosen for investigation within this division were selected through consultation with Framestore senior management as three of the most innovative films the company has worked on in the last three years. The films grossed between $195m and $450m and won numerous industry awards. To protect potentially sensitive information, these films will be referred to as projects A, B and C. Details of each of the projects can be found in Table 14 below.

Table 14 – Project description

	Project A	Project B	Project C
Time period	2016-2017	2017-2018	2017-2019
Duration	~14 months	~13 months	~17 months
Number of staff involved	~300	~300	~200
Number of staff days	~20,000	~30,000	~20,000

3.4.4. Data collection and analysis

Seven distinct types of data were collected for this study (see Appendix 2 for data description table) which were analysed using a combination of inductive and abductive methods. Firstly, job descriptions for all roles in the film division were collected and analysed in order to assess the level of specialisation/commonality of skills required for roles in each department. This was important in understanding the range of skills diversity across each project and to be able to link interview data to participants' skills profile. Each job description was inductively coded to determine a broad set of skills required for each role (see appendix 2 for codes). These skills were linked to the department, seniority level, and where the skill was mentioned in the document – i.e. role description, main responsibilities, essential criteria or desirable criteria.

The second type of data were project schedules, which detail the full project schedule for each film on a shot-by-shot basis, alongside all key milestone and delivery dates, with breakdowns by department. These schedule documents were used to gain an understanding of the particular workflow within each project and the level of integration between departments. These documents were complemented by the crew sheets, which detail all members of staff working on each shot on a daily basis. The crew sheets were used to identify potential interview subjects, by linking the job role data to specific employees from each project.

Next, evaluation documents for each project were assessed. These documents included minutes of project evaluation meetings, project timeline and budget information and the results of internal staff surveys conducted by the firm at the end of each project. The staff surveys included both quantitative and open qualitative elements, with a breakdown of responses for each department. There were over 100 responses for each survey, with response rates of 37% for project A, 28% for project B and 63% for project C. The evaluation documents served primarily to gain an understanding of the particular challenges and successes of each project, and analysis of these documents was conducted inductively, with the purpose of understanding what was important to employees in constructing narratives of success and failure. As such, the minutes of meetings and the qualitative elements of survey responses were analysed using a thematic method (Gioia et al., 2013), where initial concepts were drawn out of the data and consolidated into broad themes (see appendix 2 for codes) which could then be followed up in interviews.

Around five hours of daily meetings were also observed by the researcher to gain a greater understanding of how knowledge is integrated in practice. Notes from these observations were not specifically analysed but were used to inform the interview questions and to provide contextual understanding of the working practises of the firm.

Finally, semi-structured interviews were conducted which specifically focused on gaining an understanding of the knowledge dynamics in the firm. Interviewees were selected from key departments, as identified through analysis of job roles, and where multiple employees worked in the same role at the same level, interviewees were selected based on the amount of time each person worked on the project. Primarily senior members for each film were selected for interview as these participants were considered to have the greatest understanding of knowledge integration across each project. More mid-level and junior staff were also interviewed to encourage insights from varying perspectives. Interviews were also conducted with Framestore senior management, including senior executives and heads of department, in order to provide contextualisation for each project. A total of 20 people were interviewed, with an average interview length of 53 minutes. Interviews were transcribed and analysed abductively using a template method (see King, 2012; King & Brooks, 2016). The template method involves producing a limited number of themes based on theoretical propositions, and then refining, discarding, or adding to these themes inductively though a process of iteration. Both *ex ante* and emergent themes are organised hierarchically, so that broad concepts identified *ex ante* can be further refined and relationships between and amongst *ex ante* and emergent themes can be established (see appendix 2 for final template and example quotes for each theme). This method is highly effective in developing theory as it allows for investigation of specific themes whilst remaining open to new insights from the data.

3.5. Findings

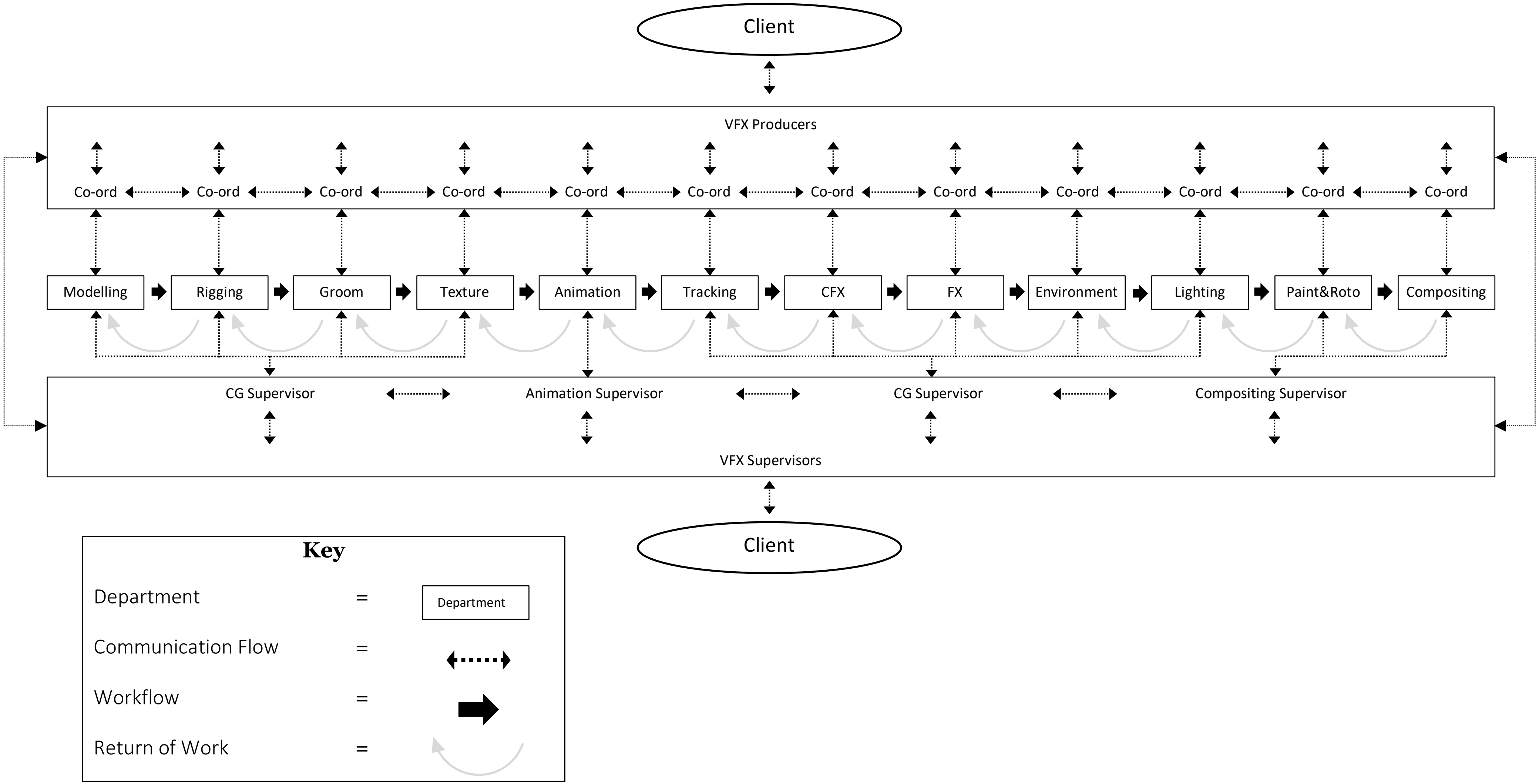
3.5.1. Specialisation: diversity vs commonality

Analysis of job descriptions shows that both creative and technical skills are required for all departments (see appendix 2 for skills breakdown by department), with more specific skills related to each job role. For example, the descriptions mentioned over 20 different types of software, and required backgrounds ranging from computer engineering to 'traditional arts'. Whilst some skills were essential for almost all roles (such as communication skills), "*the particular combination of skillsets is quite specific to each department*" (D1). As one participant explained: "*To people who don't know about the industry I like to give the example of the groom department […] it's literally all they do is put the hairs and fur on something. They don't even make it move or anything. It's so specialised*" (D2). This level of specialisation is necessary in order to produce the high quality and high volume of work that the company outputs. The high level of specialisation means that there is very little knowledge overlap in regards to specific task related knowledge. Even within a single department, tasks are varied and therefore task specific knowledge is not shared between all members of a team; "*even within a department nobody knows everything within that one department. Each one is so deep*" (D2). Moreover, there are high levels of diversity both within and between departments; "*Everyone is quite different, I think that's what works so nicely […] It's a real mixed bag, I think, of different personalities and different ways of working"* (B3).

This diversity is seen by almost all participants as positive, especially in regards to innovation; "*Especially in the early stages, you just need lots of different people with lots of different ideas*" (A2). Many participants highlighted the creative nature of the work conducted at Framestore as explicitly requiring varying viewpoints, with one participant succinctly stating: "*creativity comes from diversity*" (B6). The creative nature of the work at Framestore means that tasks are highly novel, complex and heterogeneous: "*every job we do is different and has a completely different set of challenges. You're never doing the same thing twice, ever. You have to think of new ways of doing things all the time*" (A4). As such, knowledge integration in this context is very much a process of combining many new ideas into a coherent whole. Many participants used the analogy of being cogs in a machine, with one participant describing the film division as a ‘hive mind’ (D2), where each person’s creative input enhances and augments the creative output.

Within this highly specialised environment, emphasis is placed on finding the right people for the right job and trusting others’ expertise: “*The whole idea is that you have people who do a specific job and do it really well. Then you have other people who organise the communication and everything to work together*” (A3). These ‘other people’ are the supervision and production teams, who one participant described as “*the human glue that help bring all these departments together*” (A4). Figure 7 below shows how the production and supervision teams sit across each department, and feed information both vertically and horizontally to senior team members across the departments, as well as liaising with the client – both directors and film studio executives. The production team are responsible for the more project management type tasks and the supervision team are responsible for overseeing the creative direction of the project. Alongside the communication flows, the work itself filters through each department in a highly structured order, akin to a production line. Whilst some of the early stages of work may happen concurrently, the majority of each department’s tasks are dependent on work from other departments and therefore work primarily flows downstream with the final product only fully materialising when it reaches the ‘compositing’ stage.

Figure 7 – Simplified representation of knowledge flows in Framestore



Knowledge integration therefore happens both through communication with the production and supervision teams and through the work itself, with the process requiring more interaction between departments who sit closer together in the workflow. This structure seems to work well as the majority of survey respondents felt their department 'integrated well with other departments', with 62% of project A respondents, 71% of project B respondents and 84% of project C respondents either agreeing or strongly agreeing with this statement.

3.5.2. Common Signs and Common Codes

Analysis reveals that syntactic common knowledge is largely absent at the component level, but very much present at the system level. Each department has its own jargon, which is shared by all members of that department: "*the people that we have in our team, we're all speaking a common language*" (C2). This language is picked up easily by members of that team. As one participant commented: "*you learn it quite quickly and it's used so often that you just end up learning it*" (A1). Between departments there is not much syntactic common knowledge, however, participants did not consider that a problem:

> "*There is a lot of jargon, and you get different jargon in different departments. There are certainly things that I would need to ask for an explanation of if a CFX person or a Rigger started talking to me with specifics. But then I'd be quite surprised if a Rigger started talking to me about specifics about what they were doing, because there isn't the crossover there.*" (B1)

This quote hints to the strong workflow structure described above. Many participants commented that departments who are closer together in terms of workflow require more common knowledge than departments who sit further away in the workflow. "*We all live in this world and you have to interface with them [from neighbouring departments], try to understand their language, talk their language*" (B4). This does not negate the use of department specific jargon, but at times requires a translation of language to communicate effectively. For example:

> "*One might be talking about the various muscle groups, like the corrugator action, or there is another, procerus, and the animators won't use the language. But if I just say, "Lift in the middle on the Y axis," which'll be the*

> *animation speak, there's a negative pull on the procerus muscle in the rigging language, but somewhere in between, we're all understanding each other.*" (C2)

The lack of common syntactic knowledge between departments does not hinder knowledge integration between departments, as there is a strong framework of system level syntactic common knowledge. As work flows through departments – as illustrated in Figure 7 – it is imperative that inputs and outputs of each department are standardised. This standardisation occurs through bespoke database software colloquially referred to as 'the pipeline'. As one participant describes:

> "*In order to get standardised outputs for your downstream department, all of the inputs into those processes need also to be standardised. They need to be called the same, it needs to live in the same places on your server structure. It needs to have the same attributes, sometimes the same file sizes, the same pixel counts, the same bits of data within it [...] That becomes incredibly important when you've got work that's flowing up and downstream the whole time and being iterated on*" (D4)

This standardisation across the company reduces the need for common syntactic knowledge across departments: "*None of them [in a downstream department] will know precisely what the lighters are doing in order to do their thing, but they'll know what they're expecting to get*" (A3). In addition to the pipeline, explanatory documentation is produced for all software used at the company, and show specific documentation is produced which outlines the specific requirements for shots in that show: "*We always have a Wiki page and it tells us about each character and who they are and how they work. We will look at early examples that were shown to our clients, that they liked. That is the standard that needs to be kept*" (A5). Alongside the standardised data control, the company uses project management software that enables each department and each member of staff to stay up to date on the tasks that they are required to do. Moreover, the company produces a large number of templates which aid the standardisation. The use of templates and standardised formats was mentioned by many survey respondents as being critical to the smooth running of each project and when problems had been identified in a project, many survey respondents suggested implementing further standards or templates to avoid such issues reoccurring in future work.

Adherence to the firm level standards enables knowledge integration through the work itself, with each person in each department adding or altering the shot they receive from upstream departments and outputting that shot to downstream departments. As such, the main ‘language’ necessary to understand is that of the standardised inputs and outputs, with little need to understand the full range of jargon used within the firm. Moreover, as one participant explained, whilst syntactic common knowledge is necessary to a certain extent, semantic common knowledge is more important: “*If you're working on a sequence, you've got to be able to communicate a whole range of different things. From pace and timing. You can barely even start to go through the tree of jargon. So, there's the language, but there's also the understanding what the language means.*” (C2).

3.5.3. Common Understanding and Common Indexicality

The opportunity for misunderstanding and the need for semantic common knowledge occurs at multiple points in the knowledge flow system. One participant explained how a brief from a client – usually a director – gets translated down to each employee:

> “*Production and supervisors will speak to the clients and receive the brief from them. Then, translate that brief into the tasks that need to happen within the internal team [...] Then, the individual leads for each department will see the supervisor of that department and production for that department, and they’ll just break it down into the detail of what each person will need to do*” (C1).

However, many participants commented that briefs or feedback from clients can be vague, for example “*It needs to be something that's never been seen before*” (A1) or “*Make it 50% more delicious*” (C2). These vague briefs get narrowed down through a process of idea generation and iteration. In the early stages of production clients will be shown multiple ideas and will give feedback which feeds into further iterations. However, even with these structures in place, there are times when understandings can be misaligned. One survey respondent explained the ramifications of such misalignment: “*CG sups, VFX sups and client should not all be on entirely different pages as far as what they want things to look like. It wastes so much time when the look of a shot gets approved by one sup, and then shot down by the next because they want something entirely different.*” (Survey respondent, Project A).

In order to mitigate the opportunity for misalignment between the client and supervisors, work in progress is shown to the clients at regular intervals. Work in progress is also shown to the whole film division, which many survey respondents highlighted as particularly useful in motivating staff and giving a "*sense of the momentum of the show*" (Survey respondent, Project A). Iteration is also inherent in the workflow within the film division itself. Each day employees will show the work they have been doing to their supervisor to receive comments and feedback. These daily meetings – or 'dailies' as they are known – ensure that the work employees are doing fits the brief, or the 'vison' as the supervisor interprets it. During the dailies, instructions become more specific: "*'Make this move faster,' or, 'Make this brighter,' or, 'Make that bluer'*" (D2). Here the work itself acts as a boundary object to clarify meaning: *"[the VFX supervisor] can go and say, 'I'm looking at this thing over here, and this is out of focus and this doesn't quite match it.' So you suddenly get a clearer understanding.*" (B1).

It is not just in the dailies where boundary objects are used. Many participants spoke of the importance of having good visual references when creating their work, and many used alternative methods to communicate. For example, many participants spoke about the importance of drawing: "*So, where language stops working, sometimes I just stop talking and sometimes you can just draw*" (C2), "*It's nice if you can draw and show people what you mean rather than having to use words. It's always good to be able to draw and say, 'A bit like this.*'" (A4) and many mentioned acting "*I just act it out in front of them and I say, 'Something like this. You see.'*" (B5). The use of drawing and acting is so engrained in the way that employees communicate, that many participants even used these methods during our interviews to explain the point they were trying to make.

It is clear from both the interviews and observations that boundary objects, in the form of references and the actual work itself create common semantic knowledge at the system level by ensuring that everyone understands the brief. But at the component level, 'thought worlds' are very much diverse. One participant explained why diversity of semantic knowledge at the component level is so important for innovation:

> "*The more a person is different to another in some ways is the best [...] If I put the image of a tree in your mind, maybe it will be the tree of your childhood and that one will be, as well, the tree of my childhood. It can be the same type of tree, but maybe it's different. Even this diversity, maybe I imagine the branches of the tree go in another way. This one, it's making the best because if we both are on a team and say, 'Let's do the best tree possible,' I will bring my idea, you will bring your idea and we can make something. That is usually this work, to make something out of nothing."* (C3)

The importance of having diverse frames of reference becomes clear when considering the need to interpret direction "*So, just because you understand a note, it doesn't mean that you'd be able to also do what the note is [...] You need to analyse yourself what that brief means*" (C1). One participant explains how understanding the direction of a task (system level semantic knowledge) is not as straightforward as doing exactly what you are told: "*If you give seven things that are exactly the same to seven people you get seven different things out of it. Even if you show them exactly what they have to do, it's guaranteed you'll get seven different things out of it*" (B1). In the following two quotes we see how personal interpretation and creativity is necessary to deliver a brief:

> "*The worst thing to ever do is when they come in [to a daily] and just go, 'You told me to make it pink, so I made it pink.' It obviously still looks shit and [...] it's just like you're meant to go, 'I made it pink. It clearly doesn't work, so I've done another submission where I've made it purple, which I think works quite well because of this'. The supervisors love that because it's showing that you're understanding what they're trying to get at and thinking a little bit outside the box."* (A1)

> "*You always want the artist to enjoy their work, not to just follow steps. You still want to let them try something because everyone has their own mind, own thought about things, you don't want to kill it completely.*" (B2)

Due to the inherently creative nature of the work at Framestore, we can see how a lack of component level semantic common knowledge promotes innovation though the combination and juxtaposition of differing frames of reference, interpretations and thought worlds. However, in order to ensure that knowledge integration leads to work which 'fits the brief', system level sematic common knowledge is essential. This system level knowledge is promoted through regular meetings, with the work itself acting as a boundary object to ensure that understanding of the overall direction of the work and the brief that needs to be met is consistent across people and departments.

3.5.4. Common Identity and Common Culture

There is a strong sense at Framestore that there is a common culture to everyone working in the film division. Almost all participants highlighted an overall commitment to producing good work as something shared by all employees, with many explaining that a sense of ownership over the work was an important driving force for them.

> "*There are very, very few people involved in what we do who don't want to create incredibly exciting images. That's just what they want to do. Ultimately they want people to go and see a very, very exciting movie that they've been a part of. Culturally that's what draws everybody together."* (D5)

This common culture helps in mediating local disagreements, as one participant explained: "*Because in the end, it doesn't matter. You know, like if there's an argument between a rigger and an animator, it doesn't matter who was right. Because the common goal is- the shot has to look good*" (B6). Moreover, a few participants commented that common culture overrides a lack of syntactic common knowledge: "*I find the motivations and goals are common. Like, if somebody's passionate about animation, you don't even have to speak the same language. You just get it*" (C2).

The highly specialised nature of visual effects, coupled with the strong commitment to produce high quality work means that people from different departments work together to solve problems; "*they might be struggling with a problem in FX, and they're like, 'Oh, how do we fix it', and I could go, 'Oh, we can fix that in Comp by doing this'*" (C4). The sense that everyone is working towards a common goal, also mitigates knowledge hoarding; "*At the end of the day you're passing on knowledge, it's constantly just sharing, you're constantly sharing. No one is hiding things away for themselves because that's not what it's about.*" (A5). As such, the commitment to a common goal incentivises employees to integrate knowledge and to work collaboratively to solve problems.

However, there is a diversity of priorities at the department level, and many participants expressed how each department's interpretation of what makes the best shot will be different: "*The artist wants to make something that looks incredible and does all of these things. Then the technical person says, 'It's not really possible to do that'*" (B3). In the following quote we can see that despite system level common goals, at the component level, people and departments can have very different evaluative priorities:

> "*The artistic department will be like, 'Oh, I can't do what I want because of this thing, but I don't know how to fix it. It's frustrating,' and then the technical person will be like, 'Well, no, because this is how anatomy works. This is what you should be able to do with it.' So, that's when, I*

> *think, frustrations can come into light, because one thing's not physically correct, but the other person's like, 'I don't care, magic isn't physically correct, and I need to make it look magical.'"* (C4).

Whilst competing evaluative frames can cause tension, it is generally understood that the motivations of each department are different, and that appears to be largely respected. A good example of this, mentioned by a few participants, is the need to 'break physics' – i.e. to alter the physics-based simulation models to create a more visually appealing (all be it less physically realistic) image:

> "*Typically, the creative people guiding your work want you to break physics [...] you're asked to make things look physically real, but they're ill-posed in terms of the physics. The input data and the things you're getting from some other artists just wouldn't work with a real physics model. So you have to find ways to tweak that input to make it work, without changing the intent of the animation that's being done. There's a particular creative process to create what you've been given, and you have to honour that*" (D3)

Moreover, many participants highlighted that much of their work involves problem solving, and that diversity in ways of thinking about a problem is the best way to solve it: "*there are some problems where you just need another way of thinking*" (A2). As these participants explain:

> "*A lot of the artists are really clever at finding solutions to things that, as a logical person, sometimes, you just wouldn't think of. They get a really good end result, in a very efficient way, doing something you never quite imagined would work*" (D3)

> "*Just different ways of thinking about stuff and different approaches. Solutions for things won't always come from the people who technically know everything about what you're doing. Sometimes it's more of a layman's approach, that then can be picked up by someone who actually knows how to implement it, that will actually solve the problem.*" (A3)

It is the importance of differing priorities and evaluative frames in solving problems that leads employees to seek advice outside of their specialism. Many participants highlighted that they often show work to others, both inside and outside their department, specifically to get feedback from someone with different values of worth:

> “*It doesn't need, for example, to be a visual effects artist. It needs to be another perspective [...] They can literally help because it's another perspective on an object. You take the hint that you cannot find by yourself because you're blind in some ways sometimes. You cannot see the whole spectrum because it's a different mentality*” (C3).

> “*We ask each other from time to time, ‘What do you think of this shot?’ We show you a play blast of what it looks like. A person could say to me who’s very technical, ‘Look what I've done, I've done blah-blah-blah.’ I could say, ‘Yes, but that would not work. That would not happen in real life. You wouldn’t get that motion of hair doing that in real life.’ There are certain things that you could look at as an artistic point of view and say, that’s not believable. The effect is great, what you're doing, but you just know that is not believable to the eye.”* (A5)

Here we see that it is not only different frames of reference, interpretation and thought worlds (component level semantic knowledge) that promotes innovation, but that differing evaluative priorities are often necessary to solve problems and to produce work which fits both a creative and technical brief. Moreover, the strong common culture at the system level at Framestore ensures that competing values of worth do not lead to conflict, as the goal of all employees is shared. This is particularly evident in the way in which competing evaluative priorities are negotiated between departments and that alternative values of worth are specifically sought out by employees to improve their work.

3.5.5. Mapping the interplay of common and diverse knowledge in Framestore

Overall, we can see that at Framestore knowledge at the component level is largely diverse, but that there is strong system level common knowledge which draws employees together. The use of standards (system level syntactic knowledge) is central to the way in which Framestore manages its knowledge flows. In keeping with Carlile’s (2004) observations, the standards and formal syntax of the firm are necessary for the *transfer* of knowledge between departments, ensuring that knowledge is sent and received effectively. However, we also see evidence of diversity in syntactic knowledge at the component level. Whilst some degree of common syntactic knowledge was deemed necessary at the component level to transfer knowledge between departments at Framestore, a lack of this type of common knowledge did not seem to greatly hinder the knowledge integration process. What seemed far more important to employees was the meaning taken from the syntax – semantic common knowledge. Having system level semantic common knowledge was seen as far more important for communication across knowledge boundaries. As such, we see evidence of multiple examples of boundary objects institutionalised as part of the firm's everyday working practices. Moreover, we see evidence of the work itself acting as both a boundary object and an epistemic object (Ewenstein & Whyte, 2009), by serving as a physical reference point when explicating instructions – e.g. during the dailies – while also conveying a generalised, evolving sense of direction across the workflow, as each department interprets the work in its own way. With boundary objects serving to produce a shared understanding of the expectations of the work, component level semantic knowledge was free to be diverse. Here we see different interpretations, frames of reference and thought worlds being key to how Framestore collectively produces new ideas. It is this lack of common understanding that enables knowledge augmentation and ultimately leads to new ideas and unexpected combinations. This is also true of component level pragmatic knowledge, in that diversity of evaluative priorities aids in problem solving and pushes the work to fulfil a number of different requirements simultaneously. Moreover, we find evidence of a very strong common culture in the firm which draws everyone together. The shared goals of employees fosters a sense of trust that everyone is working towards the same outcome, which helps to reduce conflict. Table 15 below maps the different types of knowledge at Framestore and indicates their role in the knowledge integration process.

Table 15 – Mapping knowledge types at Framestore

	Diverse or common	Positive or negative effect on KI	Positive or negative effect on innovation	Produces	Negative effect mediated by	Operates through
Component syntactic	Diverse	-	-/+		Standards	Jargon
Component semantic	Diverse	-	+	New ideas	Clear direction	Interpretation
Component pragmatic	Diverse	-	+	Problem solving	Trust	Evaluative frames
System syntactic	Common	+	+	Standards		Software, templates, wikis
System semantic	Common	+	-	Clear direction	Diversity of component level semantic knowledge	Boundary objects
System pragmatic	Common	+	-/+	Trust		Ownership of work

3.6. Discussion and conclusion

This paper has suggested that common knowledge is not a singular entity of which there can be ‘more or less’, but rather that there are different forms of knowledge which may be either common or diverse. It has presented a novel theoretical framework which explicates the difference between syntactic, semantic and pragmatic knowledge at the system and component level. By applying this framework to processes of knowledge integration in the visual effects industry, the paper demonstrates that it is possible to have common knowledge in some areas, and to have knowledge diversity in other areas. Moreover, the paper demonstrates that the interplay of these different forms of common and diverse knowledge shape how knowledge is integrated and new knowledge is formed.

By applying the theoretical model outlined in this paper to the knowledge integration processes of Framestore, we can begin to unpick where knowledge is different and where it is common. From this we can see that language is not the same as understanding and understanding is not the same as priorities. We can also see how commonality at the system level mitigates some of the challenges of diversity at the component level. More specifically, in the context of a highly innovative VFX firm, the paper finds that system level syntactic, semantic and pragmatic common knowledge are required for knowledge to be integrated smoothly, but that a lack of semantic and pragmatic common knowledge at the component level promotes innovation and creativity.

As much of the extant literature suggests, diversity of thought worlds (Dougherty, 1992) leads to different interpretations of a brief (Brun et al., 2008) which encourages innovation by expanding the repertoire of ideas that can be drawn upon and combined (Tiwana & Mclean, 2005) in developing creative content. Moreover, different evaluative priorities, or different conceptions of what constitutes worth (Stark, 2011), aids in problem solving, as the work is scrutinised from multiple different standpoints, creating a "synthesis of contradictions" (Nonaka & Toyama, 2003, p.3). However, as Bilton and Leary observe, "creative processes thrive in a disciplined framework" (2002, p.62), and we see the importance of strong common knowledge at the system level in providing this disciplined structure. Strong syntactic common knowledge in the form of standards and templates, ensures that in cross-functional working each person knows the technical specifications to which their work must adhere. This enables work to be passed between departments without encountering the 'glitches' in expectations that Postrel (2017) describes as one of the key failing points of cross-functional integration. Similarly, from a creative perspective, strong semantic common knowledge at the system level ensures that outputs from individuals keep within the confines of the creative brief. The distinction here between component and system level semantic knowledge is particularly key, as an understanding of the overall direction of a task is not the same as having differing interpretations of how that task should be enacted. The use of boundary objects here creates a common understanding of the brief, whilst allowing for differing frames of reference to be applied in interpretation. Moreover, we see how a common commitment to the goals of the organisation create trust that each employee is working towards the same overall outcome, which mitigates conflict and promotes collaboration. From this we can see how it is the interplay of commonality and difference which shapes how knowledge is integrated within the organisation.

That diversity encourages innovation and that commonality aids knowledge integration is not a new finding. What is novel about the theoretical framework presented in this paper is that it problematises the notion that common knowledge is a singular entity and that commonality and diversity exist on a singular spectrum. In providing a theoretically driven taxonomy of different knowledge types, the paper contributes to extant theory by expanding our conceptualisation of common knowledge to specifically include the interplay of different knowledge types. As such, it is a useful tool in progressing our understanding of how diversity and commonality interrelate within an organisation.

The paper presents a single exploratory case study, which was designed primarily to develop theory. As such, the finding of the specific combinations of knowledge types and levels might not be generalisable, in that it might not always be the case that component level semantic common knowledge is less important to knowledge integration than system level semantic common knowledge. Indeed, the setting of the study in a large firm, with well-established protocols and explicitly creative outputs might inhibit the specific findings of this study from being generalisable to other firms or to other industries. However, the fact that it was found that both commonality and difference can occur in each of these knowledge types demonstrates that the framework presented in this paper may be useful in furthering our understanding of knowledge integration processes. Moreover, it demonstrates that knowledge diversity and knowledge commonality should not be viewed as a simple spectrum but that it is a combination of diversity and commonality in different knowledge areas that shapes the knowledge integration process. Further work could look to apply this framework in different settings and could specifically focus on the effect of differing knowledge, relation and task characteristics (see Table 12) on the interplay of common/diverse knowledge types.

4. Working with the Creative Industries: Knowledge Base Combinations in Publicly Funded Collaborative R&D Projects

Abstract: The importance of the creative industries to regional and national innovation systems is becoming increasingly recognised. Moreover, the 'fusion' of creative arts and STEM (science, technology, engineering, and mathematics) skills has been shown to be a key driver of innovation and firm growth. However, it has been suggested that creative industries firms are less likely to engage in formal R&D practices than firms in other sectors. This exploratory paper assesses the extent to which innovation policy in the UK is providing opportunity for creative industries firms to engage in formal R&D collaborations with firms from STEM sectors and how such collaborations might differ from projects which involve less sectoral variety. By examining all collaborative R&D grant awards made by the UK government via its innovation agency InnovateUK between 2004 and 2020, the paper presents robust evidence that creative businesses in the UK are receiving funding for collaborative R&D projects, but that only a small minority of collaborative R&D projects involve firms from both creative arts and STEM knowledge bases. Moreover, the paper finds that such 'fused' projects typically involve more participants, take longer to complete and cost more than non-fused projects. These findings challenge the notion that creative industries firms do not engage in formal R&D practices and that the creative industries merely play a peripheral role in innovation systems. However, it also suggests that innovation policy could do more to target funding toward fused collaboration which requires greater resources to overcome differences in learning and to integrate knowledge across institutional, organisational and disciplinary boundaries.

Keywords: R&D; Creative Industries; Knowledge Bases; Innovation Policy

4.1. Introduction

The aim of this exploratory paper is to assess the extent to which innovation policy in the UK is providing opportunity for creative industries firms to engage in formal R&D collaborations and whether collaborations between creative arts and STEM (science, technology, engineering and mathematics) based firms differ to projects which involve less sectoral variety. Evidence suggests that the creative industries are one of the most innovative sectors of the economy (Bakhshi & McVittie, 2009; Müller et al., 2009) and a driver of innovation more generally throughout multiple sectors (Bakhshi & McVittie, 2009; Potts, 2009). Much of the innovative activity seen in the creative industries has been found to occur through networking and collaboration between firms in this sector (Brown et al., 2000; Colapinto & Porlezza, 2012; Gundolf et al., 2018). Moreover, it has been found that the most innovative firms in the creative industries are those that combine, or 'fuse' creative arts and STEM knowledges (Siepel et al., 2016, 2019), and that firms benefit from combining innovation efforts with firms from different 'knowledge bases' – industry sectors with different 'ways of doing innovation' (Asheim, 2007; Tödtling & Grillitsch, 2015; Manniche et al., 2017; Boschma, 2018; Grillitsch et al., 2019). However, little is known about the extent to which creative industries firms collaborate with organisations outside of the sector or engage in 'fused' collaborations – i.e. collaborations which combine creative arts and STEM knowledges. Moreover, a bias towards science and technology based definitions of R&D (Bakhshi et al., 2010; Bakhshi, 2017), coupled with strong reliance on tacit knowledge in creative industries innovation (O'Connor, 2004), means that R&D efforts of firms in this sector are often overlooked (Stoneman, 2010). For example, recent work finds that while the majority of creative industries firms do conduct some form of research and development activities, this activity is not captured by the UK definition of R&D for tax credits purposes (Bird et al., 2020). This suggests that the innovation arising from collaboration between creative industries and non creative industries firms may not be being formalised as R&D and subsequently may not be being captured and understood.

There is currently little data surrounding the extent to which creative industries firms engage in formal R&D collaborations with non-creative partners and whether such collaborations differ in nature to collaborations between firms from the same knowledge base. This paper addresses the gap in extant work, by mapping the distribution of publicly funded R&D collaborations between creative industries firms and a range of different actors, including non creative industries firms, academic, and public sector institutions, using UK Government data which details all InnovateUK funded projects between 2004-2020. The paper specifically answers two questions: To what extent are creative industries firms involved in publicly funded R&D collaborations? And do collaborations which 'fuse' creativity with STEM differ to collaborations involving firms from the same knowledge base?

The paper contributes to extant literature by firstly offering evidence as to the extent of creative industries involvement in publicly funded R&D collaborations in the UK. This is important in understanding the impact of innovation policy at a national level and in identifying ways in which such policy could be better targeted towards creative industries firms. Additionally, the paper contributes to the burgeoning distributed knowledge bases literature, by exploring the characteristics of collaboration projects which combine knowledge bases in formal R&D programmes. This element of analysis furthers our understanding of knowledge base combinations, by investigating their characteristics in the context of publicly funded R&D programs and can inform the design of innovation policy to better capitalise on the benefits of knowledge base combinations.

4.2. Empirical and theoretical context

4.2.1. Distributed and combinatorial knowledge bases

The distributed knowledge bases literature arose in the early 2000s out of innovation studies and economic geography literatures to explain how different modes of innovation and learning arise in different industries due to their underlying knowledge base (Boschma, 2018). This strand of research developed the argument that sectoral variety improves economic growth not only by minimising risk (the so called portfolio effect), but through improving the innovation capabilities of firms, by extending the opportunity for cross sectoral networks and the opportunity to combine knowledge in novel ways (Frenken et al., 2007; Broekel et al., 2017).

Since Penrose (1995), there has been an understanding that firms possess heterogeneous resources and capabilities, and many scholars have framed inter-firm collaboration as a way to access resources and capabilities beyond the boundaries of the firm (Eisenhardt & Schoonhoven, 1996). However, the distributed knowledge bases literature suggests that it is not just access to resources and capabilities, but the combination of different institutional logics or 'ways of doing innovation' (Asheim, 2007; Tödtling & Grillitsch, 2015; Asheim et al., 2017), that contributes to the development of new knowledge, products and services. Asheim (2007) distinguishes between three key knowledge bases: analytic (science based), synthetic (engineering based) and symbolic (creativity based). The distinction between these three relies less on the type of product or service created, but instead centres around "varying learning modes, approaches to reasoning and criteria for validation of knowledge" (Manniche et al., 2017, p.453).

According to Asheim (2007), the *analytic knowledge base* comprises of knowledge which is generally formed through formal R&D processes, and mainly concerns codified knowledge inputs and outputs. In this type of knowledge base, both basic and applied research are relevant and firms often work with universities or research institutes to develop or capitalise on scientific discoveries. The *synthetic knowledge base* comprises of knowledge which is generally formed through the combination and application of existing knowledge to solve specific problems. Applied research is far more relevant to this type of knowledge base than basic research, and innovation usually occurs through adaptation and practical working. The *symbolic knowledge base* comprises of knowledge which is primarily aesthetic or cultural. Here knowledge production processes involve largely context specific tacit know-how and a deep understanding of cultural norms and values. Development in this knowledge base often involves project-based work, but with less clearly defined goals than in the other two knowledge bases.

Whilst most industries will draw on all knowledge bases to some extent, there are sectoral differences in regards to which knowledge base dominates in any given industry. For example, the analytic knowledge base is commonly associated with life sciences such as biotechnology, the synthetic knowledge base with engineering sectors such as advanced machinery and the symbolic knowledge base with creative industries such as advertising and marketing (Květoň & Kadlec, 2018). By combining knowledge bases in networking and collaboration efforts, firms do not just gain access to additional resources and capabilities, but draw on different approaches to learning, problem solving and knowledge creation (Grillitsch et al., 2019). As such, R&D collaborations between firms from different knowledge bases can improve the innovation capabilities of all firms involved and can lead to more innovative outputs than collaborations between firms who share a knowledge base (Tödtling & Grillitsch, 2015).

Accordingly, the combinatorial knowledge bases literature suggests that promoting strong innovation systems at a regional and national level requires policy which encourages collaborations between firms from different knowledge bases. This requires collaboration not only between the analytic and synthetic knowledge bases – i.e. science and engineering sectors – which have historically received the greatest attention in regards to innovation policy (Jaaniste, 2009), but also significant involvement of the symbolic knowledge base, which is overwhelmingly comprised of the creative industries (Cooke & De Propris, 2011).

4.2.2. R&D in the creative industries

The creative industries are a group of industry sectors which "have their origin in individual creativity, skill and talent and which have a potential for wealth and job creation through the generation and exploitation of intellectual property" (DCMS, 2001).

They comprise of a range of different subsectors such as music and performing arts; TV, film and radio; advertising and marketing; publishing; and software design (see appendix 1 for full definition). While heterogonous, the creative industries as a group differ from other sectors of the economy in a number of key ways. Crucially, the creative industries all produce goods and services which deliver cultural or symbolic value (Throsby, 2008a). This means that creative organisations must balance tensions between creative and economic priorities and create innovation processes which allow for the ambiguity and dynamism necessary to produce goods and services whose value cannot always be objectively assessed (Lampel et al., 2000). Consequently, innovation processes to develop creative goods and services are very different from STEM based industries (Jisun, 2010). For example, the creative industries rely heavily on tacit knowledge (O'Connor, 2004) and experimentation (Caves, 2000; Bakhshi et al., 2010). Moreover, as the majority of creative industries firms produce outputs which are inherently new, innovation is often central to the business model of firms in this sector (Peltoniemi, 2015). As such, we can see how the creative industries are so commonly associated with the symbolic knowledge base, as they both produce goods and services which impart symbolic value and encompass distinct approaches to innovation and learning.

Innovation within the creative industries is coming to be understood in greater detail and there is beginning to be some consideration of the role that the creative industries play in broader innovation ecosystems. For example, Green et al (2007) distinguish four key areas in which innovation occurs in the creative industries: in the development of new cultural products (e.g. films, video games etc), in the development of new cultural concepts (e.g. narratives, representations of ideas etc), in the delivery of products (e.g. new designs) and at the user interface (e.g. new ways of users experiencing a product). Similarly, Miles and Green (2008) argue that creative businesses contribute to wider innovation ecosystems by developing new business models, combining technologies in novel ways and developing new services. Moreover, it has been argued that the creative industries support innovation at the beginning of the value chain, by providing cultural assets that can be exploited by science and technology sectors in new products and services, and towards the end of the value chain through marketing and diffusion strategies (Bakhshi & McVittie, 2009). Elsewhere it has been argued that the creative industries also contribute innovation towards the middle of the value chain, by adding aesthetic value to products beyond their technical functionality. This so called 'soft innovation' has been seen to contribute to innovation in a wide variety of non-creative sectors such as food, pharmaceuticals and finance (Stoneman, 2010). Consequently, the creative industries are increasingly recognised as a vital component to resilient innovation ecosystems (Cooke & De Propris, 2011).

As much as the creative industries can contribute to innovation in other sectors of the economy, science and technology sectors are increasingly contributing to innovation in the creative industries themselves. The importance of science and technology to creative industries sectors such as software and video games design is perhaps obvious, but an increasing amount of innovation in the more traditional arts sectors, such as music, theatre and film, is also occurring through technology (Hesmondhalgh, 2018). Here, the opportunities afforded by widespread digitisation have created new markets and new ways of creating and delivering creative goods (Davies & Ward Dyer, 2019). As such, the incorporation of science and technology into creative work has been seen as the driving force behind much innovation in the creative industries over the past century (Bakhshi et al., 2012).

This all suggests that collaboration between the creative industries and STEM sectors is a key driver of innovation. Indeed, it has been found that the most innovative firms both within the creative industries (Sapsed et al., 2013; Siepel et al., 2016) and outside the creative industries (Brunow et al., 2018; Siepel et al., 2019) are those which combine or 'fuse' creativity with science and technology and that combining knowledge bases at the firm (Grillitsch et al., 2019) and regional level (Asheim et al., 2011) leads to economic growth. Yet despite evidence of the benefits of fusing creative arts and STEM, there has been relatively little attention paid to individual collaboration projects between creative industries firms and firms from science, technology and engineering sectors. This perhaps reflects a general bias towards science, technology and engineering definitions of R&D which have obscured the contribution that creative industries firms may be making to R&D projects (Jaaniste, 2009; Potts, 2009). Consequently, we do not know the extent to which UK innovation policy is providing opportunity for creative industries firms to engage in formal R&D collaborations, nor the extent to which they are entering such collaborations with firms in STEM sectors – i.e. 'fused' collaborations.

4.2.3. Collaborative R&D projects

Whilst inter-firm collaboration is nothing new, there has been a steady rise in the number of formal inter-firm R&D collaborations in recent years (Hagedoorn, 2002; Martínez-Noya & Narula, 2018). Firms can benefit from such activities as collaboration pools resources, minimises risks associated with innovation and promotes learning (Kogut, 1988; Hagedoorn et al., 2000). Moreover, there has been a growing acknowledgement of the role of academia and public research institutes in supporting innovation ecosystems (D'Este & Patel, 2007) and policy has increasingly sought to promote a 'triple helix' model (Etzkowitz & Leydesdorff, 2000) of innovation by encouraging collaborations between firms, academia and public sector organisations. As such, much innovation policy at a local, regional, national and international level has been targeted towards promoting a diverse range of R&D collaborations through subsidised programs which have been shown to positively impact firms' networking and innovation capabilities (Almus & Czarnitzki, 2003; Czarnitzki et al., 2007; Hottenrott & Lopes-Bento, 2014; Broekel et al., 2017).

In keeping with the increased policy interest in R&D collaboration, there is a growing literature on 'open innovation' strategies, encompassing a range of different types of collaboration agreements from strategic alliances, to joint ventures, to R&D outsourcing (Narula & Martínez-Noya, 2015; Martínez-Noya & Narula, 2018), both between firms and between firms and academic or public institutions (Perkmann et al., 2013). In general, collaborations have been shown to increase an organisation's innovation capabilities, by extending the organisation's knowledge, networks and collaboration skills, and minimising the risk of R&D by sharing the costs associated with innovation (Martínez-Noya & Narula, 2018). However, for collaborations to be successful, key barriers between organisations must be overcome.

Boschma (2005) argues that cognitive, organisational, social, institutional and geographical proximity between organisations has a significant baring on the success of collaboration. When organisations are far apart on these dimensions of proximity, communication, coordination and lack of trust can impede successful learning. Alternatively, too much proximity can hamper the opportunity for novel idea generation and compound lock-in and inertia. Indeed, research which has considered collaborations between differing partner types, such as competitors, suppliers, customers, and academic and public research institutes, finds that differing combinations of types of collaborative partner have a significant effect on the innovative outcomes of such projects, as there are substantial challenges to working with partners who have different organisational and institutional logics (Fritsch & Franke, 2004; Kang & Kang, 2010; Belderbos et al., 2018; Lind et al., 2013; Bjerregaard, 2010). Moreover, there is a wide literature on the difficulties involved in overcoming a lack of cognitive proximity and bridging knowledge boundaries, as organisations require a degree of common knowledge in order to successfully communicate and absorb knowledge from external partners

(Cohen & Levinthal, 1990; Grant, 1996b; Mowery et al., 1996; Lane & Lubatkin, 1998; Berggren et al., 2017; Tell et al., 2017).

In relation to collaboration across knowledge bases specifically, institutional and cognitive barriers come to the fore. Here, industry and disciplinary norms, in relation to innovation processes and the validation of knowledge, may lead firms from different knowledge bases to have differing modes of working and differing conceptions of project success. Moreover, the lack of a common knowledge base between firms could significantly hamper communication and understanding between collaboration partners. Consequently, collaboration projects between firms from differing knowledge bases may be riskier and require greater resources to manage in regard to both time and money than projects involving firms from more similar industries.

In seeking to gain a greater understanding of the extent to which UK innovation policy is supporting fused collaborations, it is therefore also important to consider how these projects differ in scope and scale to non-fused projects.

4.3. Data and methods

4.3.1. Data description

In assessing the extent to which innovation policy in the UK is providing opportunity for creative industries firms to engage in formal R&D collaborations and whether fused collaborations differ to projects which involve less sectoral variety, this paper uses a publicly available dataset compiled by the UK government, which details all InnovateUK funded projects between 2004-2020 (Innovate UK, 2020). InnovateUK are a UK government body who award funding to businesses, organisations and individuals to promote R&D and innovation across the economy. They fund a number of different types of award, including awards specifically for collaborative R&D projects. As InnovateUK is the government's primary vehicle for funding innovation, this dataset represents a significant proportion of all public R&D funding in the UK.

Over the 17 years covered in the dataset used in this paper, Innovate UK funded collaborative R&D projects across 536 different competitions, each of which had a different focus for research. Eligibility for awards varied between competitions, with some targeted specifically towards SMEs, some requiring collaboration with academic partners etc. As such, this dataset represents investment by InnovateUK in their areas of interest and whilst the data also includes many open calls, much of funding allocated has been for specific programs of work. The dataset provided by InnovateUK includes information about all types of funded project and details of each organisation involved, including a Company Reference Number (CRN) for every company who has been awarded funding through the organisation. The CRN enables the matching of data from InnovateUK to firm level data from Companies House and the FAME database. By linking the InnovateUK dataset to firm level databases it was possible to ascertain both industry classifications (SIC codes) and further firm details such as firm size.

A number of cleaning steps were initiated before the InnovateUK dataset was matched with additional data from the FAME and Companies House databases. Firstly, as this paper is solely interested in R&D collaborations, all non-R&D collaboration awards were excluded from the dataset. Secondly, all organisation types were checked in order to correctly identify UK firms, as opposed to academic institutions, public sector organisations, non-UK firms, etc, who would not be classified in the business databases. The CRN for each UK firm was then cross-referenced against Companies House and the FAME database to ensure that the correct CRN had been recorded by InnovateUK. Finally, for any firm with a missing or incorrect CRN, a valid CRN was established by matching the company name and address provided in the InnovateUK data with records from Companies House and FAME. The final dataset comprised of 5,241 R&D collaboration projects, involving 7,045 unique organisations. Of these organisations 6,538 are UK firms, with the remaining organisations being non-UK firms, academic institutions, public sector organisations (PSOs), public sector research organisations (PSREs), NHS bodies or charities.

4.3.2. Methods

The paper presents two main areas of analysis. Firstly, descriptive statistics detail the extent to which creative industries firms are present in the data and some characteristics of the projects which creative industries firms are involved in. This includes both summary statistics and network visualisations depicting the interrelation of firms within projects. In operationalising the creative industries, the paper follows the widely used DCMS classification of the creative industries (DCMS, 2016), which is defined at 4 digit SIC level (see appendix 1 for list of creative industries SIC codes). The remaining industry sectors are classified according to the main UK SIC sections A-U. Creative industry sectors are removed from the main SIC sections, so for example the main section J (Information and Communication) only includes those SIC codes which are not already included in the creative industries subsector IT, Software and Computer Services.

The second area of analysis focuses on knowledge bases present in the data and the extent to which projects which fuse creative arts and STEM knowledge are different to projects which do not. This section of the analysis firstly presents summary statistics of the relative involvement of each knowledge base and the various combinations of knowledge bases. Building on extant research which finds that combining creativity with STEM knowledge leads to innovation (Sapsed et al., 2013; Siepel et al., 2016, 2019), a fused project is operationalised as a project which involves at least one partner from the symbolic knowledge base (creativity based) and at least one partner from either the analytic (science based) or synthetic (engineering based) knowledge bases. As such, the definition of a fused project used in this paper reflects an understanding of fusion drawn from empirical work and the knowledge bases literature, viewing fusion as *the combination of information and proficiencies (skills) arising from different methods of advancing knowledge (arts and sciences), that are embedded within an individual, group or organisation and embodied through action.*

In assigning knowledge base classifications to industry sectors, the paper borrows Sedita et al.'s (2017) industry classification, which identifies industry sectors which most closely resemble the ideal type of each knowledge base (symbolic, analytic and synthetic), based on firm level survey data (see Table 29 in appendix 3 for knowledge base classification). Only those sectors which display a high correlation with each knowledge base ideal type are included in the classification[17]. This classification is therefore based on actual activity of firms in each industry, rather than product output and as such is a fairly accurate method of aligning industry sectors with knowledge bases.

4.4. Findings

4.4.1. Creative industries involvement in publicly funded R&D collaborations

While extant literature has suggested that creative industries firms play a limited role in formal R&D, this paper's analysis reveals that creative industries firms are frequently being awarded collaborative R&D grants by the UK government. Table 16 below shows that around 10% of all organisations funded for collaborative projects by Innovate UK between 2004 and 2020 were creative industries firms. Of the firms funded, excluding

[17] It is important to note, that whilst the symbolic knowledge base comprises of much of the creative industries, there is a degree of mismatch between the two classifications. For example, the manufacturing of jewellery is classified as a creative industry but falls under the synthetic knowledge base classification, whereas information service activities is categorised as symbolic but does not fall under the creative industries definition.

other organisation types, creative industries firms comprise 12%. Moreover, at least one creative industries firm was involved in around 16% of all funded projects. This demonstrates that creative industries firms are contributing to a substantial proportion of publicly funded R&D collaboration projects. What is also interesting, when considering extant work, is that creative industries firms are not merely performing subsidiary roles but are found to lead collaborative R&D projects in 8% of cases. Taken together, these initial descriptive statistics suggest that creative industries firms are engaging in formal R&D collaborations and that they are playing central roles in many of these projects.

It is also worth noting that there is large variation across the creative industries subsectors, with the majority of creative industries firms coming from the IT subsector (70%), which accounts for around 7% of all organisations funded (see Table 30 in appendix 3). Considering the importance of marketisation strategy and end user application to the new product development process, it is perhaps surprising that we only find 1.8% of projects involved an advertising and marketing firm. However, we do find that all creative industries subsectors are represented in the data, suggesting that even the more traditional arts-based subsectors are engaging in formal R&D practices and are being supported by UK government policy to do so.

Table 16 – Creative industries firms funded by InnovateUK 2004-2020

	Unique organisations N [% total] (% subset)	**Unique projects** N [% total] (% subset)	**Occasions awarded** N [% total] (% subset)	**Occasions lead organisation** N [% total] (% subset)	**Total Project Funding[18]** (£M)
Creative industries	726 [10.3%]	827 [15.8%]	1040 [5.9%]	420 [8.0%]	£188.8
Advertising and marketing	12 (1.7%)	15 (1.8%)	16 (1.5%)	5 (1.2%)	£2.3
Architecture	45 (6.2%)	67 (8.1%)	71 (6.8%)	40 (9.5%)	£4.3
Crafts	1 (0.1%)	1 (0.1%)	1 (0.1%)	1 (0.2%)	£0.0
Design: product, graphic and fashion design	59 (8.1%)	75 (9.1%)	76 (7.3%)	26 (6.2%)	£21.9
Film, TV, video, radio and photography	54 (7.4%)	71 (8.6%)	84 (8.1%)	33 (7.9%)	£16.0
IT, software and computer services	511 (70.4%)	637 (77.0%)	739 (71.1%)	298 (71.0%)	£137.8
Museums, galleries and libraries	2 (0.3%)	2 (0.2%)	2 (0.2%)	0 (0.0%)	£0.0
Music, performing and visual arts	30 (4.1%)	27 (3.3%)	32 (3.1%)	7 (1.7%)	£4.2
Publishing	12 (1.7%)	19 (2.3%)	19 (1.8%)	10 (2.4%)	£2.3
Other industries	5524 [78.4%]	4827 [92.1%]	12057[68.2%]	4465 [85.3%]	£2503.5
Other organisation types*	438 [6.2%]	2916 [55.6%]	4025 [22.8%]	223 [4.3%]	£921.2
Non-UK firms	69 [1.0%]	62 [1.2%]	75 [0.4%]	2 [0.0%]	£3.4
Unknown	288 [4.1%]	452 [8.6%]	490 [2.8%]	126 [2.4%]	£69.7
Total	7045 [100%]	5241 [100%]	17687 [100%]	5236 [100%]	£3686.6

**This includes academic organisations, charities, NHS departments or trusts, public sector research establishments and other public sector organisations*

In regards to the amount of funding provided by InnovateUK to creative and non creative firms, we find that the mean grant award per organisation and per occasion funded is

[18] Note that the actual amount of funding for all projects may be slightly higher than shown here, as figures for grant awards were not available for some of the more recent projects.

lower for creative industries firms than for firms in other sectors. However, the median funding award is higher for creative firms than it is for non creative firms. When we look to Table 17, we see that the median funding award per organisation is roughly £24,000 more for creative firms than for non creative firms and the median funding award per occasion funded is roughly £20,300 more for creative industries firms. This suggests that creative industries firms are less likely to be receiving very large funding amounts, compared to firms in other industry sectors, but are not routinely receiving less financial support from InnovateUK for the projects they are involved in.

Not only is the median funding award for creative industries firms higher than for non creative industries firms, but they are also found to more frequently lead in the projects they are involved in. Table 17 shows that on around 40% of the occasions a creative industries firm has been involved in a project they have done so as the lead participant, compared to 37% for non creative industries firms. This is particularly the case for firms in architecture and publishing, which have, on average, led on the majority of projects they have been involved in (56% and 53% proportion of awards as lead respectively). These findings contest extant conceptions of creative industries as subsidiary R&D partners and provide important evidence that creative industries firms are no less likely to lead on projects than firms from other industry sectors, and are in fact playing a central role in many of the collaborations they are involved in.

However, when we look to how frequently firms were funded multiple times, we see that on average creative industries firms were funded 1.4 times, whereas non creative industries firms were funded on average 2.2 times. This finding perhaps fits with the notion that formal R&D partnerships are less central to the way in which firms in this sector innovate and may represent more of a 'one off' as opposed to a regular mode of practice. Interestingly, Table 17 also shows that other organisation types are funded on average 9.2 times, which is largely due to academic organisations, primarily universities, being funded on average 26.4 times (see Table 31 in appendix 3). Academic organisations are however very rarely lead participants, leading on only 4% of the projects they are involved in, suggesting that they play a crucial but more peripheral role in collaborations.

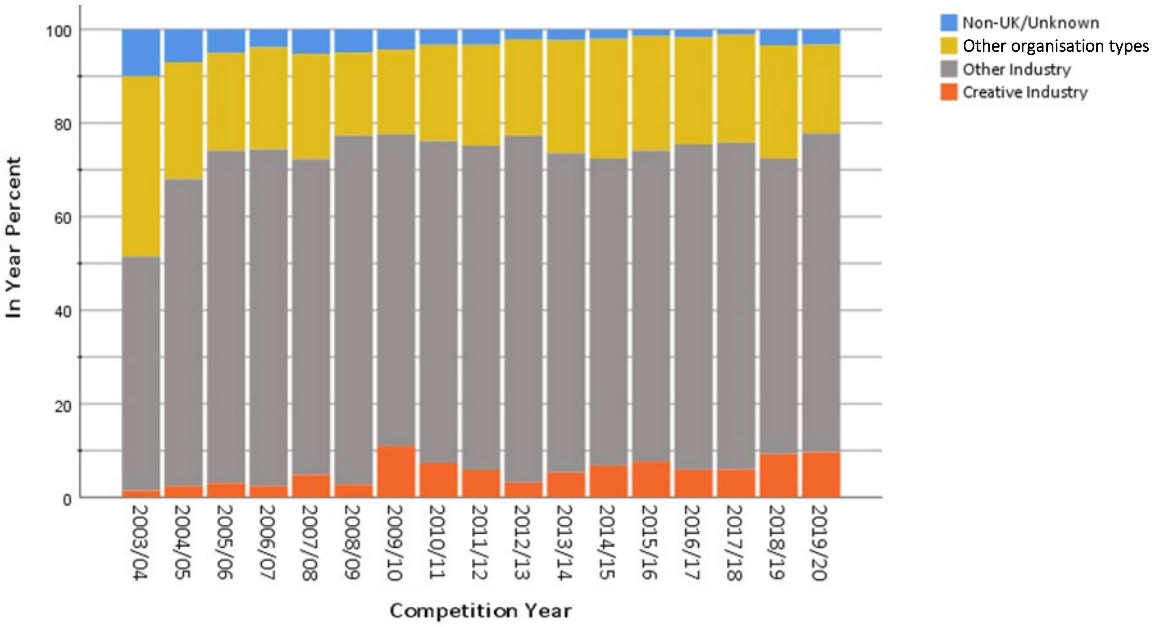
Table 17 – Funding awards

	Unique awards per organisation (N)	Proportion of awards as lead (%)	Mean* funding per organisation (£)	Median* funding per organisation (£)	Mean* funding per occasion funded (£)	Median* funding per occasion funded (£)
Creative industries	1.43	40%	£260,551	£129,594	£195,255	£114,000
Advertising and marketing	1.33	31%	£192,020	£45,162	£144,015	£46,649
Architecture	1.58	56%	£95,945	£56,085	£64,441	£56,085
Crafts	1.00	100%	£0	£0	£0	£0
Design: product, graphic and fashion design	1.29	34%	£371,502	£75,572	£332,101	£94,336
Film, TV, video, radio and photography	1.56	39%	£295,526	£132,016	£204,595	£137,489
IT, software and computer services	1.45	40%	£270,425	£142,234	£199,766	£124,968
Museums, galleries and libraries	1.00	0%	£0	£0	£0	£0
Music, performing and visual arts	1.07	22%	£139,882	£61,982	£131,139	£72,498
Publishing	1.58	53%	£189,805	£127,142	£126,537	£114,950
Other industries	2.18	37%	£453,138	£105,504	£223,426	£93,656
Other organisation types**	9.19	6%	£2,103,241	£185,100	£244,226	£131,886
Non-UK	1.09	3%	£49,963	£0	£52,234	£0
Unknown	1.70	26%	£241,880	£34,304	£151,768	£41,408
Total Population (for reference)	*2.51*	*30%*	*£523,296*	*£104,227*	*£223,852*	*£100,000*

*Note that mean and median figures have been calculated only for those projects where funding information was available.
**This includes academic organisations, charities, NHS departments or trusts, public sector research establishments and other public sector organisations.

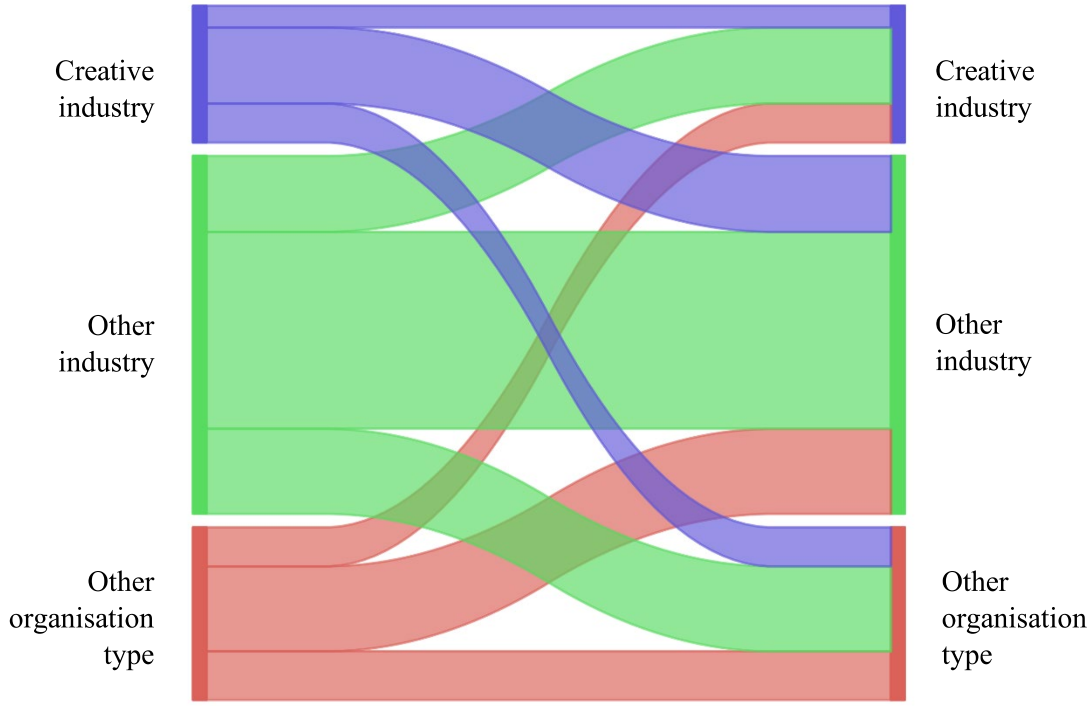
Looking at the changes in funding awards over time (Figure 8), there has been an increase in the proportion of creative industries firms receiving funding during the 17 years covered in the data. In the funding year 2003/4 only 2% of funded firms were creative industries firms, but by 2019/20 that had risen to 10%. While there is some fluctuation between years, there does appear to be an upward trend in the proportion of awards made to creative industries firms. This perhaps reflects the high growth of the creative industries in the UK over the last few decades, with creative industries employment growing at over three times the rate of the UK as a whole from 2010 to 2018 (DCMS, 2019b).

Figure 8 – Proportion of awards per competition year by organisation type



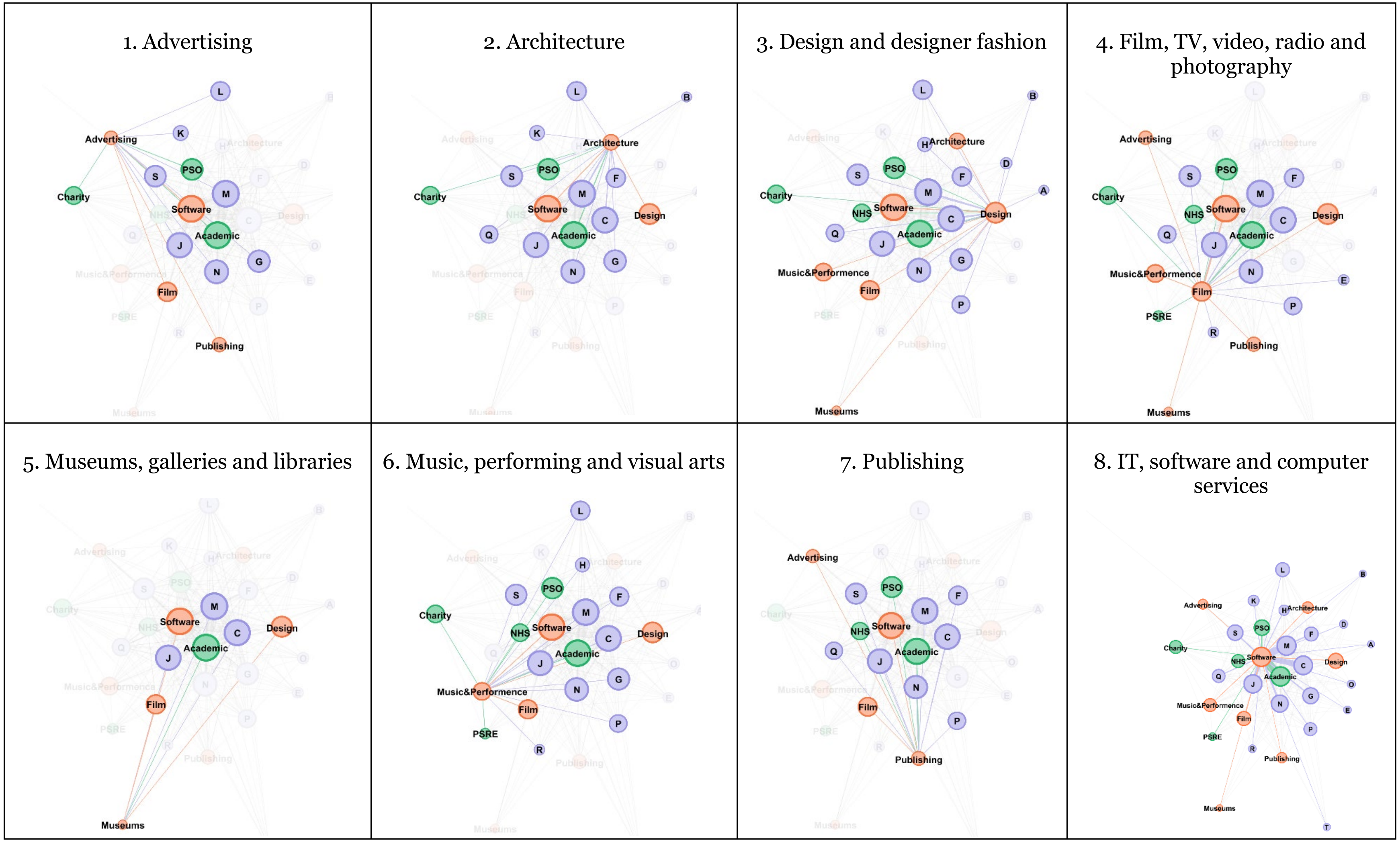
Having established that creative industries firms are involved in a substantial proportion of R&D collaborations funded by InnovateUK, that this proportion is growing, and that creative industries firms are often playing lead roles in such projects, analysis now turns to which types of organisations creative industries firms are working with. Figure 9 gives a visualisation of how often different types of organisations work with each other in collaborations. It shows that the majority of collaboration involving creative industries firms occurs between creative industries and non creative industries firms, with only 19% of all projects involving a creative industries firm involving multiple creative industries partners. As literature suggests that collaboration between creative industries firms is an integral aspect of the structure of many of these industries, it is perhaps surprising that we find a relatively small amount of intra-creative industry collaboration in this dataset. It could well be the case that in collaborations between creative industries firms, less formal collaboration arrangements are more common than the formal arrangements captured in this data.

Figure 9 – Cross-industry collaboration

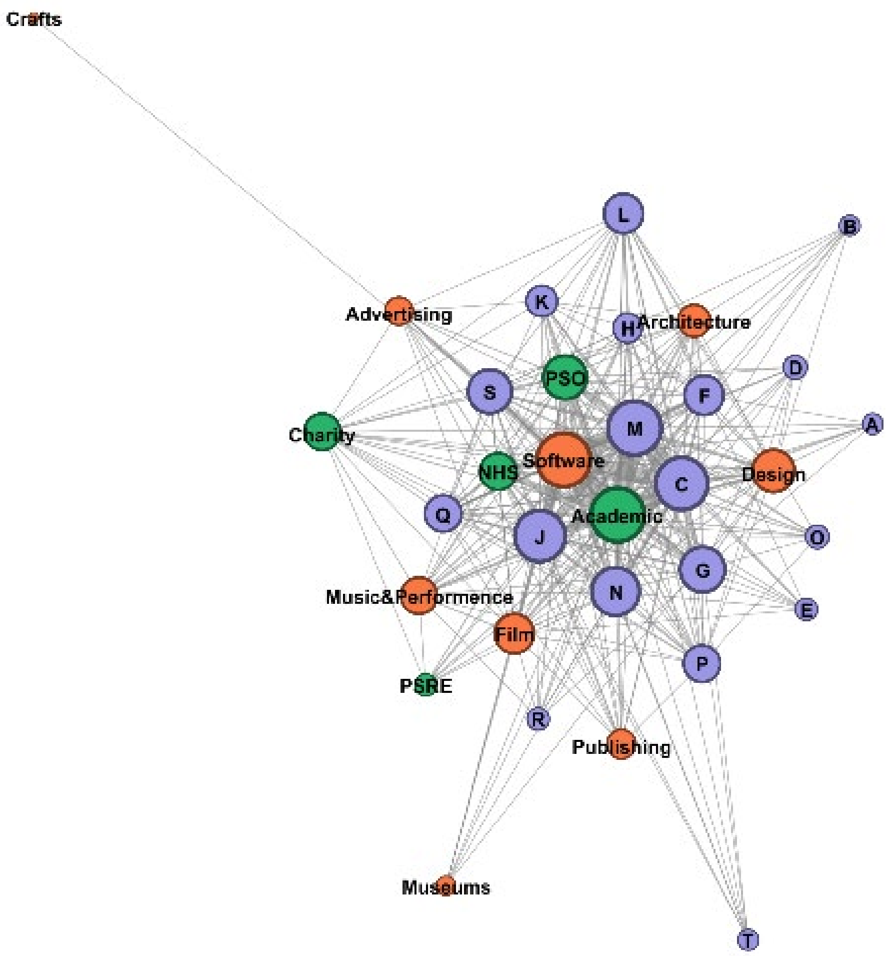


To explore inter- and intra-industry collaboration in greater depth, Figure 10 depicts the collaboration networks for projects which involved at least one creative industries firm, with visualisations 1-8 highlighting the collaboration networks for each subsector of the creative industries and visualisation 9 showing the collaboration network for all creative industries firms. In each visualisation, nodes represent instances of firms' involvements in projects aggregated by industry and edges represent instances when firms from different industries have been involved in a shared project. The size of the node indicates the number of times that firms from an industry group have been involved in projects, with larger nodes denoting a greater number of firms involved in collaborations. The width of an edge indicates the number of times that collaborations between distinct industry groups have occurred. Finally, the distribution and clustering of nodes indicates the strength of relationships between industry groups within the network as a whole.

Figure 10 – Creative industries projects network visualisations



9. All creative industries subsectors



Key:
Advertising = Advertising and marketing
Design = Design and designer fashion
Film = Film, TV, video, radio and photography
Software = IT, software and computer services
Museums = Museums, galleries and libraries
Music&Performance = Music, performing and visual arts
A = Agriculture, Forestry and Fishing
B = Mining and Quarrying
C = Manufacturing
D = Electricity, Gas, Steam and Air
E = Water Supply; Sewerage, Waste
F = Construction
G = Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles
H = Transportation and Storage
J = Information and Communication
K = Financial and Insurance Activities
L = Real Estate Activities
M = Professional, Scientific and Technical Activities
N = Administrative and Support Service Activities
O = Public Administration and Defence
P = Education
Q = Human Health and Social Work Activities
R = Arts, Entertainment and Recreation
S = Other Service Activities
T = Households as Employers; Undifferentiated Goods- and Services
Academic = Academic organisations
NHS = National Health Service organisations (e.g. hospital trusts etc)
PSO = Public sector organistaion
PSRE = Public sector research establishment

The visualisation shows that different subsectors have very different collaboration networks. Firstly, there is variation across subsector networks in regard to the amount of collaboration with other creative industries subsectors. For example, we can see that the architecture subsector (visualisation 2) works with relatively few of the other creative industries subsectors, only working with design firms around 2% of the time and IT, software and computer services firms around 10% of the time. The remainder of their collaboration ties are with firms from other sectors, with the strongest ties being to firms in Professional, Scientific and Technical Activities sector (28% of collaboration ties), Manufacturing (14% of collaboration ties), and Construction (12% of collaboration ties). Whereas, the film, TV, radio and photography sector (visualisation 4) has been involved in collaboration projects with firms from almost all other creative industries subsectors, the most common of which are IT, software and computer services (19% of collaboration ties), music, performing and visual art (6% of collaboration ties) and publishing (2% of collaboration ties).

In regards to intra-industry collaboration ties, we find that film, TV, radio and photography has the highest intra-industry collaboration ratio, with 9% of collaboration ties from firms in this subsector being other firms in this subsector. We find comparatively little intra-industry collaboration in the advertising sector, which has only 2% of its collaboration ties with other advertising firms.

When looking at diversity of collaboration partners, we also find variation across networks. The creative industry subsectors with the largest number of firms in the dataset, IT, software and computer services and design, have the most diverse networks, with software firms collaborating with firms from almost all industry sectors and design working with firms from 14 different non-creative industries sectors. Interestingly, we see the highest proportion of inter-industry collaboration ties from design firms with firms from the Manufacturing industry (23% of ties) and the Professional, Scientific and Technical Activities sector (19% of ties), which are far higher than the proportion of ties with any other creative industries subsector, suggesting that design services are a key way in which creative firms add value to other sectors of the economy.

In regards to other types of organisation, we see a strong academic involvement across almost all subsector collaboration networks, with collaboration ties with academic institutions ranging from 14% of all architecture collaboration ties to 23% of all publishing collaboration ties. We also see some unexpected collaborations with NHS organisations, with firms from both the film, tv, radio and photography subsector and the music, performing and visual art subsector having been involved in a collaboration project with an NHS organisation.

This visualisation also shows which sectors are most central to the overall creative industries collaboration network. Visualisation 9 depicts the collaboration network for all projects involving a creative industries firm in its entirety. Here, we see the software subsector is highly central to the collaboration network, with museums and crafts at the periphery. We also see which subsectors are closer together, demonstrating denser collaboration ties. For example, music, performing and visual art are close to film, TV, radio and photography – indicating a higher frequency of collaboration – but relatively far away from design – indicating a lower frequency of collaboration. The importance of academic partners to the network is also evident by their central position in the network, as is the importance of Manufacturing, Professional, Scientific and Technical activities and the remaining Information and Communication industry sectors.

4.4.2. Knowledge base combinations and fused projects

Having investigated the role of creative industries firms specifically, analysis turns to the combination of knowledge bases and examination of fused projects. Table 18 shows the different knowledge base combinations present across all funded projects. The dominance of the analytic knowledge base is clear, with just over 46% of all projects involving at least 1 analytic partner. This is in keeping with the knowledge bases literature which stresses the reliance on formal R&D practices for analytic firms. Similarly, the symbolic knowledge base, which the knowledge bases literature suggests is the least likely to engage in formal R&D, has the lowest involvement in projects, with only 20% of funded projects involving symbolic firms. Moreover, in collaborations involving more than one knowledge base, symbolic firms are least likely to be leads. That being said, the fact that symbolic firms are involved in formal R&D collaborations at all is an interesting finding and around 12% of all projects involved a symbolic firm with no analytic or synthetic representation.

When looking at the combination of knowledge bases, we find that analytic and synthetic are the most common combination, with just under 17% of projects involving both analytic and synthetic firms. This is far higher than combinations involving symbolic firms. Indeed, only 2% of projects involve all three knowledge bases and only 8% of projects are found to be 'fused projects' – i.e. involve a symbolic firm partnering with either an analytic or synthetic firm. This suggests that knowledge base combinations are occurring, but that the majority of those combinations are not of the type that has been specifically linked to innovation.

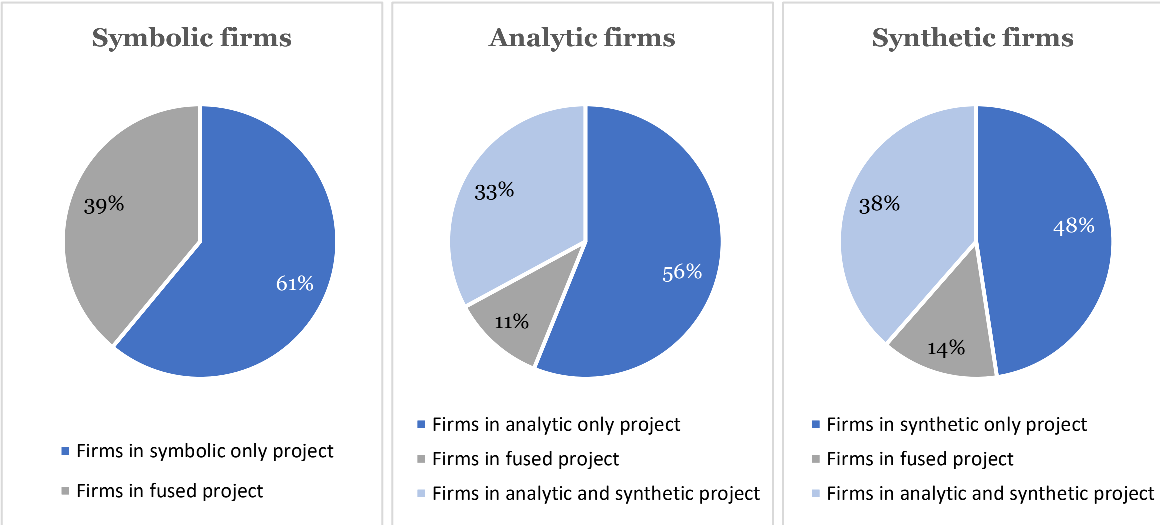
Table 18 – Knowledge base combinations

Fused/ Non-fused	Knowledge bases represented	Unique projects N (% of total)	Knowledge base of lead (% within row)		
			Analytic	Symbolic	Synthetic
Fused	Symbolic and Analytic Only	134 (2.6%)	35.10%	29.10%	0.00%
	Symbolic and Synthetic Only	162 (3.1%)	0.00%	23.50%	42.60%
	All three knowledge bases	119 (2.3%)	21.00%	19.30%	29.40%
	Total Fused	*415 (7.9%)*	*17.30%*	*24.10%*	*25.10%*
Non-Fused	No Analytic, Synthetic or Symbolic	1068 (20.4%)	0.00%	0.00%	0.00%
	Analytic Only	1407 (26.8%)	82.9%	0.0%	0.0%
	Symbolic Only	610 (11.6%)	0.00%	74.30%	0.00%
	Synthetic Only	972 (18.5%)	0.00%	0.00%	72.20%
	Analytic and Synthetic Only	769 (14.7%)	41.40%	0.00%	38.50%
	Total Non-Fused	*4826 (92.1%)*	*30.80%*	*9.40%*	*20.70%*
Total		5241 (100%)	29.70%	10.60%	21.00%

While the total proportion of Symbolic Only projects is lower than the proportion of Analytic Only and Synthetic Only, Figure 11 shows that a higher proportion of symbolic firms are working within their knowledge base. We find that 61% of symbolic firms are involved in projects which do not include an analytic or synthetic partner, compared to 56% of analytic firms working only with other analytic firms and 48% of synthetic firms working only with other synthetic firms. In other words, firms from a symbolic knowledge base are least likely to collaborate with firms from other knowledge bases.

However, when looking at Figure 11, we also see that although more analytic and synthetic firms are entering collaborations with other knowledge bases, the majority of these collaborations do not involve a symbolic partner.

Figure 11 – Proportion of firms involved in each project type



Now we have established the prevalence of fusion in inter-firm collaborations, analysis turns to the extent to which these collaborations differ from other projects. Although there are far fewer fused projects than non-fused projects, we do find some significant differences in the characteristics of these two project types. Table 19 below shows that the average fused project has almost twice as many participants as the average non-fused project (6.2 participants compared to 3.1 participants), indicating that fused projects are generally larger in scope than non-fused projects. Interestingly, we also find that fused projects have a higher proportion of firms as collaboration partners (81.5% compared to 77.3%) and a smaller proportion of academic involvement (15.6% compared to 18.9%), when compared with non-fused projects. However, fused projects do include one academic partner on average, indicating that academic involvement is more common in fused projects than in non-fused projects (where the average number of academic partners is 0.6).

Table 19 – Organisation types in fused and non-fused projects

	Mean n		Mean % of all organisations involved in a project	
	Fused	Non-fused	Fused	Non-fused
All participants	**6.20**	**3.13**	100%	100%
Academic	**1.01**	**0.62**	**15.6%**	**18.9%**
Charity	0.01	0.01	0.1%	0.6%
NHS	**0.09**	**0.03**	0.7%	0.8%
PSO	**0.17**	**0.04**	1.8%	1.3%
PSRE	0.01	0.02	0.2%	0.7%
Non-UK	0.00	0.02	0.1%	0.4%
UK Firms	**4.74**	**2.31**	**81.5%**	**77.3%**

Note: T-test difference in means significant at p<0.01 in bold

We also see significant differences between fused and non-fused projects in regards to the size of firms involved (Table 20 below). Fused projects tend to have more large firms, with an average of 42% of firms involved in a fused project being large compared to an average of 34% of firms involved in a non-fused project being large. Similarly, we find a smaller proportion of micro firms involved in fused projects (19%) compared to non-fused projects (26%). This is also reflected in the costs attributed to firms, with a higher proportion of project costs attributed to large firms in fused projects than large firms in non-fused projects. This indicates that large firms are having greater involvement in fused projects than small and micro firms, perhaps reflecting the ability of larger firms to dedicate resources to overcoming the institutional, organisational and cognitive barriers associated with collaboration across knowledge bases.

Table 20 – Average number of firms in fused and non-fused projects by firm size

	Mean *n*		Mean % of all firms involved in a project		Mean % of project costs allocated to firms	
	Fused	**Non-fused**	**Fused**	**Non-fused**	**Fused**	**Non-fused**
Large	**2.05**	**0.92**	**41.9%**	**34.4%**	**41.2%**	**33.5%**
Medium	**0.59**	**0.30**	12.4%	12.5%	12.5%	12.4%
Small	**1.22**	**0.61**	25.9%	27.2%	28.4%	28.4%
Micro	**0.88**	**0.48**	**19.8%**	**25.9%**	**17.9%**	**25.7%**

Note: T-test difference in means significant at p<0.01 in bold

In keeping with this, we also find that fused projects are, on average, a lot more expensive than non-fused projects. The average total grant awarded to fused projects is around £792,000 more than non-fused projects and the average total project costs is around £1,311,000 more than non-fused projects. This fits with the finding that fused projects tend to have more partners, indicating that fused projects are generally larger in scale. Similarly, we also find that fused projects have a longer project duration than non-fused projects, with the average fused project duration being around 4 months longer than the average non-fused project.

Table 21 – Average project grant, costs and length for fused and non-fused projects

	Fused	**Non-fused**
Total project grant award (£)	1,432,647	640,712
Total project costs (£)	2,429,048	1,117,614
Project length (days)	847	736

Note: T-test difference in means significant at p<0.01 for all statistics shown

As fused projects include symbolic firms by definition, it is also of interest to explore any differences found between fused projects, non-fused projects and projects only involving symbolic firms. Table 22 compares fused projects to projects involving only the symbolic knowledge base, and other projects which are not fused. Here we find that symbolic only projects have, on average, significantly fewer participants, are awarded less in grant funding and cost less overall than either fused projects or projects not involving a symbolic firm. Symbolic only projects are also significantly shorter on average than fused projects or projects not involving a symbolic firm. This indicates that it is not the presence of a symbolic partner in a project per se which correlates with higher costs and longer project duration, but that it is the combination of symbolic and analytic/synthetic partners which correlates with larger scale projects.

Table 22 – Comparison of symbolic only, fused and other project grant, costs and length

	Mean no. participants	Mean total project grant (£)	Mean total project costs (£)	Mean project length (days)
Symbolic Only	3.00	475,818	818,853	581
Fused	6.20	1,432,647	2,429,048	847
Other	3.15	664,570	1,160,841	759

Note: T-test difference in means significant at p<0.01 for all statistics shown

However, it could be the case that larger costs and longer project duration associated with fused projects is a function of the greater number of participants involved. To test the extent to which this may be the case, a simple probit regression was conducted to explore how project cost, duration and number of participants intersect. Table 23 shows the marginal effects of these three variables on the likelihood of a project being fused, with the inclusion of dummy variables for competition year to minimise the effect of variation across different funding calls. From this we can see that fused projects are associated with higher costs, even when controlling for project length and number of participants involved. Project length, however, does not significantly correlate with likelihood of being a fused project when participant numbers are held constant, suggesting that project duration may have more to do with the nature of projects with high numbers of participants, than to the nature of fused projects.

Table 23 – Project level probit regression of likelihood of a project being fused

	(1)	(2)	(3)
Competition year dummies	*Included*	*Included*	*Included*
Total project cost (£M)	0.007***	0.005***	0.002**
	(0.001)	(0.001)	(0.001)
Project length (years)		0.011***	-0.002
		(0.004)	(0.003)
Number of project participants			0.021***
			(0.001)
Observations	5,241	5,241	5,241
Pseudo R^2	0.038	0.041	0.176

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Finally, we explore further the differences in type of participant involved in fused projects by conducting a probit regression at the participant level, with each case being a single firm in a single project (Table 24 below). Here marginal effects are calculated for the likelihood of a firm being involved in a project which is fused, when controlling for competition year, firm size and grant award. Additionally, model 2 assesses the marginal effects of being previously funded by InnovateUK for a project, and model 3 assesses the marginal effects of being previously funded for a fused project. Models 4 and 5 introduce industry sector to the regressions, exploring the likelihood of being in a fused project for a subset of analytic and synthetic firms (4), and a subset of symbolic firms (5). These last two models have been applied to subsets of the data so that meaningful comparisons can be made between industry sectors within the knowledge base classifications.

The probit results in Table 24 show some interesting findings. Firstly, we see no significant correlation between grant award and likelihood of being in a fused project, meaning that although fused projects cost more overall, the amount of money each participant in a fused project is awarded from InnovateUK does not differ substantially from the amount of money awarded to each participant in a non-fused project. This finding is important as, taken together with the finding that fused projects cost more than non-fused projects, it implies that organisations themselves are having to invest more in projects which are fused.

We can see that whether firms had been involved in InnovateUK funded R&D collaborations in the past has no significant effect on their likelihood to be involved in a fused project. However, having previously been involved in a fused project specifically does positively correlate with being involved in a fused project again. This relationship is especially marked for firms from a symbolic knowledge base. It could be very tentatively suggested that this implies participants generally have a positive experience of fused projects, as those who have been involved in a fused project are found to be more likely to do so again, and that this is especially the case for creative firms.

In keeping with the t-test on firm size presented in Table 20, this analysis also finds that firm size has a significant baring on likelihood of being involved in a fused project, with likelihood decreasing in line with decreases in firm size. Moreover, this relationship becomes stronger when introducing industry sector to the regression. Here we find that firm size has a larger effect on likelihood of entering a fused project for firms in the analytic and synthetic knowledge base than for all firms when not controlling for industry sector, and that size has an even greater effect for firms in the symbolic knowledge base. For example, we find that micro firms in the symbolic knowledge base are around 14% less likely to be involved in fused projects than large firms from this knowledge base. This could potentially be related to the greater costs involved with fused projects, found in the previous regression, in that smaller firms have less working capital to invest in more expensive projects.

We also find some significant differences in the industry groups most likely to be involved in fused projects. Within the analytic and synthetic group, we find that firms from the finance sector are more likely to be involved in fused projects than firms from the manufacturing sector. This perhaps points to the involvement of the IT sector in finance, so called 'fintech', and suggests that fused projects may be more service based than product based. We also find interesting results for firms in the symbolic knowledge base (model 5). Whilst we find the IT, software and computer services sector is the most represented of all creative industries sectors in the data (see Table 16) and we find them to be central to collaboration networks between creative industries firms (Figure 10), model 7 shows that firms in this sector are not significantly more likely to be involved in fused projects than firms from the music, performing and visual arts sector. This implies that while the more technological parts of the creative industries are central to collaboration networks, the more traditional arts-based parts of the creative industries are just as likely to be involved in projects which fuse their creativity with science and technology.

Table 24 – Participant level probit regression of likelihood of a project being fused for all firms (models 1,2 and 3) and a subset of analytic and synthetic firms (model 4) and symbolic firms (model 5)

	(1)	(2)	(3)	(4)	(5)
Competition year dummies	*Included*	*Included*	*Included*	*Included*	*Included*
Firm size (ref. Large)					
Medium	-0.025***	-0.025***	-0.006	-0.027**	-0.054
	(0.009)	(0.009)	(0.010)	(0.011)	(0.055)
Small	-0.019**	-0.020**	0.002	-0.031***	-0.134***
	(0.008)	(0.008)	(0.008)	(0.010)	(0.043)
Micro	-0.035***	-0.037***	-0.004	-0.057***	-0.145***
	(0.008)	(0.008)	(0.009)	(0.011)	(0.045)
Grant (£M)	-0.003	-0.003	-0.006	-0.006	0.006
	(0.005)	(0.005)	(0.006)	(0.007)	(0.039)
Previously funded		-0.004			
		(0.007)			
Previously in fused project			0.102***	0.100***	0.267***
			(0.010)	(0.013)	(0.039)
Analytic and synthetic industries (ref manufacturing)					
K: Financial and Insurance Activities				0.253***	
				(0.054)	
L: Real Estate Activities				0.176***	
				(0.066)	
M: Professional, Scientific and Technical Activities				-0.011	
				(0.009)	
N: Administrative and Support Service Activities				0.208**	
				(0.097)	
Symbolic Industries (ref CI: IT, software and computer services)					
CI: Film, TV and Radio					-0.211***
					(0.051)
J: Information and Communication (excluding CI Subsectors)					-0.024
					(0.031)
CI: Music, performing and visual arts					-0.021
					(0.096)
CI: Publishing					-0.144
					(0.107)
R: Arts, Entertainment and Recreation (excluding CI Subsectors)					0.353**
					(0.160)
Observations	12,614	12,614	12,614	6,317	1,246
Pseudo R^2	0.019	0.019	0.031	0.055	0.108

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.5. Discussion

The aim of this paper was to assess the extent to which innovation policy in the UK is providing opportunity for creative industries firms to engage in formal R&D collaborations and whether publicly funded R&D collaborations which ‘fuse’ creativity with STEM differ to collaborations involving firms from the same knowledge base. As the fusion of creativity with science and technology in publicly funded R&D collaborations is a novel area, the paper has presented primarily descriptive and exploratory findings, rather than strict hypothesis testing. That being said, the paper makes a number of significant findings.

The paper finds robust evidence that creative industries firms do engage in formal R&D collaboration. It finds that 12% of all firms funded by InnovateUK between 2004 and 2020 were creative industries firms, and that creative industries firms were involved in 16% of all funded projects. While the majority of these firms were from the IT, software and computer services subsector, it is encouraging to find that funding had also been awarded to a substantial number of firms from subsectors such as music, performing and visual arts, and film, TV, radio and photography. As much literature argues that innovation in the creative industries is difficult to capture using traditional R&D metrics (Stoneman, 2010; Bakhshi, 2017), it is significant that this paper finds creative industries firms engaging in formal R&D practices. In addition, the paper finds that creative industries firms have a higher proportion of lead involvement than firms from other industries, with creative industries firms leading projects 40% of the time they are involved in a project. This demonstrates that the creative industries are not merely adjuncts to the R&D efforts of firms in other sectors but are a driving force in many R&D projects. Moreover, as organisations who perform a leading role, or are more central in a collaboration network, have been shown to gain greater access to ‘innovation-relevant knowledge’ (Broekel et al., 2017, p.300), creative firms may be gaining greater innovation competencies through their collaborations than firms who are less often leads.

In regard to the combination of knowledge in collaboration projects, the paper finds that the majority of R&D collaboration funded by InnovateUK involves partners from within the same knowledge base. This is particularly the case for firms from the symbolic knowledge base, who collaborate with firms outside their knowledge base less frequently than analytic or synthetic firms. This may be due to the fact that projects involving a symbolic and an analytic or synthetic firm – i.e. a fused project – represent a greater investment from firms in regard to both time and money. The paper finds that fused projects typically involve more participants, take longer to complete and cost more than non-fused projects. Moreover, the paper finds that the higher costs associated with fused projects are not solely due to the greater number of participants involved or the longer duration of such projects. Fused projects may be more costly overall as greater resources need to be spent overcoming differences in learning and integrating knowledge across cognitive, institutional and organisational boundaries.

These additional costs may help to explain why we find larger firms being more likely to be involved in fused projects, as they have greater resources to invest in such efforts. The striking correlation between firm size and involvement in a fused project is particularly concerning in regard to creative industries firms. The creative industries are characterised by a high concentration of small and micro businesses (McKinlay & Smith, 2009; Jones et al., 2015; Virani & Pratt, 2015). As such, this sector may be particularly disadvantaged in undertaking fused collaboration projects if such endeavours require significantly more investment than intra-industry collaborations.

Overall, the paper finds strong evidence that creative businesses in the UK are receiving government funding to partake in collaborative R&D projects, and that they are playing a central role in such collaborations. This complicates the notion that creative industries firms do not engage in formal R&D and demonstrates that creative firms are in fact the driving force in many R&D projects. However, the paper finds that only 8% of collaborative R&D projects involve the fusion of creativity with science, technology and engineering which has been shown elsewhere to foster innovation and growth. As such, innovation policy should look to target funding specifically for fused R&D projects and could look at ways to encourage smaller business to get involved in such projects. As this paper finds that being involved in a fused collaboration in the past increases the likelihood of being involved in a fused project in the future, a short term, targeted approach to promote fused collaboration could see sustained increases in this type of project in the future. Focusing innovation policy towards fused R&D would greatly strengthen the UK's innovation capabilities and promote growth for not only the creative industries, but across innovation ecosystems.

4.6. Conclusion, limitations and directions for future research

Amongst increasing awareness of the value of the creative industries to the global economy, and commitments from research bodies and government funding agencies to do more to support the continued growth of the sector, this paper provides a much-needed assessment of the public funding of R&D activities conducted in collaboration with creative industries firms. It is important to point out however, that the analysis conducted in this paper examines public funding for collaborative R&D that is primarily competition based and therefore dose not represent the full scale of collaborative R&D activity that may be occurring without such support. Moreover, as each competition will have different eligibility criteria, many creative industries firms may not be eligible to apply for funding through this route. As such, the results presented in this paper should be considered indicative of UK innovation policy priorities, rather than the ability or willingness of firms to engage in such collaborations.

That said, by examining all collaborative R&D funding provided by the UK government through InnovateUK for a 17-year period, the paper presents robust evidence that creative industries firms do engage in formal R&D practices and that they are receiving funding from the UK government to do so. However, it has been shown that collaboration projects which ‘fuse’ creative arts and STEM knowledge, which has been identified in the literature as promoting innovation, are less frequently funded. This raises many further questions as to why this may be the case, only some of which have been explored in this paper. The exploratory nature of this paper has limited its ability to explore the differences found between fused and non-fused projects in any great depth. Future work could look to corroborate and extend these findings by conducting more extensive analysis on the characteristics of firms involved in fused projects and the reasons for their involvement. Future work could also look to link involvement in fused collaboration projects to project outcomes, to find out the extent to which fused projects are more challenging and/or more innovative. This could be achieved through linking the dataset used in this paper to more detailed firm level data, surveying firms involved in these projects or conducting qualitative fieldwork with a range of upcoming projects.

5. Discussion and conclusion

5.1. Paper findings and contribution summaries

5.1.1. Paper 1 summary – What is the relationship between STEAM education and graduate employment outcomes in the UK creative industries?

The first paper presented in this thesis examined graduate outcomes for those who had studied a combination of creative arts and STEM qualifications across further and higher education. Whilst there has been some examination of arts graduates' role in the creative industries (Comunian et al., 2011; Bloom, 2020) and some examination of gradate outcomes for those studying a joint honours or double major degree (Pitt & Tepper, 2012; Pigden & Moore, 2018), there has hitherto been a lack of evidence concerning the outcomes of graduates with a specific combination of creative arts and STEM qualifications (fused graduates), and the role that such graduates play in supporting the creative industries. The paper theorises that fused graduates contribute to innovation in the creative industries, by acting as boundary spanners between diverse experts; bridging the gap between social, linguistic and cognitive domains and facilitating communication and the integration of ideas. As much literature has espoused the benefits of STEAM education (Bequette & Bequette, 2012; Land, 2013; McAuliffe, 2016), and grey literature has suggested that the particular combination of creative arts and STEM skills is increasingly required for creative work (Neelands et al., 2015; Cultural Learning Alliance, 2017; Bakhshi et al., 2019), establishing the relationship between STEAM education and work in the creative industries is an important step towards gaining a greater understanding of how education policy could be targeted towards supporting the creative industries.

The paper found that around a third of graduates working in the creative industries and around a third of graduates working in creative occupations had a fused skillset, compared to just under a quarter of graduates working outside the creative industries or in non-creative occupations. Moreover, the paper finds that there are more fused graduates working in the creative industries and in 'specialist' roles – i.e. creative occupations within the creative industries – than graduates with a solely STEM or solely creative arts based education. This is clear evidence of a link between skills fusion and future employment in creative sectors. It also supports the argument that fused graduates contribute to innovation in these sectors through boundary spanning activities, as they are most likely to work in roles central to the sector. However, the paper also finds that although 22% of graduates are Fused at pre-HE level, only 1% of graduates show evidence of fusion at HE level, with only 0.2% of graduates having completed a joint honours degree comprised of separate creative arts and STEM components. This suggests that higher education is acting as a bottleneck for fusion, limiting students' ability to gain high level fused skills.

Consequently, this paper contributes to our understanding of how the fusion of creative arts and STEM skills contributes to innovation in the UK creative industries, by evidencing the prevalence of fused graduates in the creative work force and suggesting that skills fusion at the firm level may be being supported by fused graduates at the individual level who act as boundary spanners between creative arts and STEM specialists.

5.1.2. Paper 2 summary – How does the interplay of different forms of common and diverse knowledge shape processes of knowledge integration in the UK creative industries?

The second paper presented in this thesis examined the interplay of common and diverse knowledge in processes of knowledge integration. It develops a framework of different types of knowledge, which can be either common or diverse, and applies this framework to the case of a highly innovative firm in the visual effects industry. Extant work on group and organisational level diversity tends to concede that diversity is beneficial for innovation, but that it creates challenges to cohesive teamwork (West, 2002). As such, skills diversity tends to be viewed as a 'trade-off' between the need for diverse knowledge to increase the repertoire of knowledge that can be drawn upon for innovation, and common knowledge to enable the successful integration of knowledge across knowledge domains (Cohen & Levinthal, 1990; Mengis et al., 2009; Erkelens et al., 2010). However, rather than viewing diversity/commonality as a spectrum, something of which a firm can have either more or less, the paper proposes that multiple dimensions of knowledge commonality and diversity can be at play within the context of a firm. By delineating these different forms of knowledge, we can see how it is possible to hold common knowledge in one of these areas but lack common knowledge in another.

In applying the theoretical framework developed in the paper, findings demonstrate that the interplay of different forms of common and diverse knowledge shape how knowledge is integrated and new knowledge is formed. The paper finds that, in the context of a large visual effects company, syntactic, semantic and pragmatic common knowledge are required at the system level for knowledge to be integrated smoothly, but that a lack of semantic and pragmatic common knowledge at the component level promotes innovation and creativity. That diversity encourages innovation and that commonality aids knowledge integration is not a new finding. What is novel about the theoretical framework presented in this paper is that it problematises the notion that common knowledge is a singular entity and that commonality and diversity exist on a singular spectrum.

In providing a theoretically driven taxonomy of different knowledge types, the paper therefore contributes to our understanding of how the fusion of creative arts and STEM skills contributes to innovation in the UK creative industries at the firm level by theorising how the interplay of different forms of common and diverse knowledge lead to innovation.

5.1.3. Paper 3 summary – To what extent is innovation policy in the UK supporting creative industries firms in engaging in formal R&D collaborations with firms from STEM sectors and how do such collaborations differ to projects which involve less sectoral variety?

The final paper presented in the thesis explored the extent to which innovation policy in the UK is providing opportunity for creative industries firms to engage in formal R&D collaborations and whether collaborations between creative and STEM based firms differ to projects which involve less sectoral variety. Despite increased awareness of the innovative activity of firms in the creative industries (Stoneman, 2010), there remains a conception that creative industries firms do not engage in formal R&D practises, but rather rely on more informal forms of research and development activities (Bakhshi et al., 2010). Moreover, when creative firms have been considered in regards to formal R&D practices, this has largely been in regards to their supporting role to science and technology sectors (Jaaniste, 2009). As such, there has been little research to date which specifically looks at the prevalence of formal R&D practices in the creative industries, or the characteristics of projects involving both creative firms and firms from STEM sectors.

The findings of the paper indicate that creative industries firms do engage in formal R&D practices and that they are receiving funding from the UK government to do so. Moreover, it finds that creative industries firms are often playing a central role in collaborative R&D projects, thus dispelling the myth that creative firms contribute to innovation systems only as adjuncts to science and technology sectors. However, the paper finds that the majority of R&D collaboration funded by InnovateUK involves partners from within the same knowledge base, and only 8% of collaborative R&D projects involve partners from both creative and STEM sectors. This may be due to the fact that fused projects represent greater demands in regards to both time and money. The paper finds that fused projects typically involve more participants, take longer to complete and cost more than non-fused projects. Moreover, the paper finds that the higher costs associated with fused projects are not solely due to the greater number of participants involved or the longer duration of such projects. Fused projects may be more costly overall as greater resources need to be spent overcoming differences in learning and integrating knowledge across institutional, organisational and disciplinary boundaries. This may be why we find larger firms being more likely to be involved in fused projects, as they have greater resources to invest in such efforts. The correlation between firm size and involvement in a fused collaboration found in this paper is perhaps most concerning when we consider the structure of the creative industries, which are characterised by a high proportion of small and micro firms (McKinlay & Smith, 2009; Jones et al., 2015; Virani & Pratt, 2015). This all suggests that while some inter-firm level fusion is being supported by government grants, innovation policy in the UK could be doing more to target policy towards encouraging fused R&D projects and greater involvement in such projects by small and micro businesses.

Consequently, the findings of this paper contribute to our understanding of how the fusion of creative arts and STEM skills contributes to innovation in the UK creative industries, by demonstrating that inter-firm level fusion is occurring in the context of publicly funded collaborative R&D, but that such projects only form a small proportion of InnovateUK's portfolio and that such projects represent a greater outlay of resources – both time and money – when compared to projects which involve less sectoral variety.

5.2. Findings synthesis and discussion

5.2.1. How does the fusion of creative arts and STEM skills contribute to innovation in the UK creative industries?

Taken together, these findings present an illuminating picture of how the fusion of creative arts and STEM skills are contributing to innovation in and around the creative industries. As discussed in the introduction chapter to this thesis, recent research has indicated that firms who combine creative arts and STEM skills in their work are more innovative and grow faster than firms who rely on a singular skillset and/or knowledge base. However, it was posited that we remain unclear how this relationship develops; how does the fusion of creative arts and STEM skills contribute to innovation in the UK creative industries?

The findings of this thesis suggest that skills fusion contributes to innovation primarily by offering a wider range of viewpoints from which to draw in the development of new ideas. The findings of paper 1 reveal that while joint honours degrees in both creative arts and STEM subjects are incredibly rare in the UK context, having at least some education from both arts based and science based disciplines correlates highly with employment in the creative industries and creative occupations. This suggests that creative industries workers, though likely to be predominately trained in a specific disciplinary area, are also more likely than other workers to have some experience and learning within a second disciplinary area, enabling them to better bridge social, linguistic and cognitive gaps between knowledge domains. This finding becomes incredibly important when we look to the firm level analysis in the thesis. Here we find that disciplinary boundaries between workers within a firm do exist, but that innovation occurs through a mix of both common and diverse knowledge. It is disciplinary specialisation of employees which provides the firm with a range of ideas and perspectives, and it is the exposure to differing disciplinary approaches which each employee has that ensures individuals are able to coalesce around group or firm level objectives. As such, we can see how fusion at the individual level directly contributes to fusion at the firm level, by enabling individuals to understand and respect other viewpoints. Moreover, the findings of the thesis also indicate how this translates to inter-firm level fusion. If firms require an amount of prior related knowledge to be able to successfully absorb new knowledge, then we can see how skills fusion at the firm level could lead to more successful inter-firm collaborations. The findings of paper 3 suggest that fused collaboration projects take longer and are more costly than non-fused projects. However, if creative industries firms develop capabilities in fusing creative arts and STEM skills at the firm level, they may have to expend fewer additional resources in overcoming differences in knowledge and learning styles when working with firms from other industry sectors.

The findings of the three papers also offer insight into heterogeneity across the subsectors which make up the creative industries. Some subsectors, such as Architecture, are found to have a high concentration of fused individuals working in firms in this sector and are well represented in the InnovateUK collaborative R&D grant data. Similarly, the subsector film, TV, radio and photography is found to be highly fused at the individual level and firms from this sector are found to be involved in highly heterogenous collaboration networks. This indicates that subsectors where the use of technology and engineering are essential components of everyday working practices, such as the case firm in paper 2, are more likely to require fusion to operate. However, we also find that there is substantial amounts of fusion taking place at the more creative end of the spectrum, with music, visual and performing arts showing a high concentration of fused workers and substantial involvement in collaborative R&D projects. This indicates that despite differences in the structure and dynamics of subsectors of the creative industries, fusion appears to be beneficial for firms across subsectors.

Consequently, the findings presented in this thesis suggest that the combination of creative arts and STEM skills at the individual, firm and inter-firm level drives innovation across all subsectors of the creative industries by increasing the diversity of knowledge and perspectives that can be drawn upon in the development of new ideas, while facilitating group cohesion and knowledge integration.

5.2.2. Is fusion a trade off?

While the findings of the thesis indicate that fusion is beneficial for innovation, that is not to say that skills fusion is exclusively positive. A common theme in all three papers of this thesis is the supposed trade-off between diversity and specialisation, with increased diversity being beneficial for innovation, but being challenging in regards to communication and bridging between differing world views. However, the findings of paper 2 specifically explain how diversity in some knowledge domains and commonality in other knowledge domains drives innovation. Here the findings suggest that what is most beneficial for innovation is a combination of common and diverse knowledge. As paper 1 demonstrates, workers in the creative industries are likely to come from a range of backgrounds. Some will have entirely STEM based education, some entirely creative arts based education and some will have both arts and STEM qualifications at a lower level, and either arts or STEM qualifications at a higher level. Moreover, these skills will evolve throughout a person's career and will be augmented by further training and work experience. We can think of these different education and career pathways as providing different 'knowledge contexts' representing different forms of knowledge from different disciplinary perspectives, encompassing a unique range of ideas, concepts, languages, methodologies and approaches to learning. It is the combination of the accumulated knowledge context of each individual which provides the foundations on which innovative collaboration can emerge. The more diverse these knowledge contexts are, the more opportunities there will be for some areas of knowledge to be common and some areas of knowledge to be diverse.

What fusion at an early stage of education provides is exposure to different approaches to learning and ways of viewing the world. However, it is heterogeneity and the 'dissonance' (Stark, 2011) which arises from 'colliding and competing' ideas, perspectives and viewpoints which is crucial for innovation. Moreover, if all members of a firm had equally fused skillsets then, as Erkelens observes "parties are not able to learn from each other because knowledge is too related and not new" (Erkelens et al., 2010, p.93). As such, specialisation is also important in fostering a depth of knowledge and enabling strong disciplinary approaches to be utilised in the collective endeavour; if all workers in a firm were individually perfectly fused, then the firm would no longer have knowledge heterogeneity within its workforce. Meyer and Land's (2003) notion of a threshold concept is particularly relevant here. A threshold concept is an idea within an academic discipline that once learned transforms a person's understanding of the world, leading to "the transformation of personal identity, a reconstruction of subjectivity [...] a shift in values, feeling or attitude". Crucially, these threshold concepts cannot be 'unlearned'. As such, through exposure to threshold concepts from differing disciplines, individuals may be able to better understand each discipline, but will be forever transformed through the process. Consequently, the understanding and reflexive positionality of fused individuals negates the opportunity for strong paradigmatic opinion, which can lead to productive conflict.

We see this too at the inter-firm level. Collaboration between creative and non-creative firms can be productive not only due to the cumulation of diverse resources, or the specific disciplinary/industry specific knowledge that each party provides, but because it combines different approaches to learning and innovation. Organisations, much like individuals, have a knowledge context – the cumulation of its workers expertise and the embedded memory of routines and day-to-day practices (Kogut & Zander, 1992). This knowledge context will inform an organisation's approach to learning, which can supersede that of an individual. As such, an organisation which has employees with different skillsets will still have a unitary organisational culture, or 'way of doing things'. Much like at the individual level, in inter-firm collaborations it is the fusion of diverse ways of approaching a task, alongside the specific skills of organisational members which fosters innovation through the combination of distinct knowledge bases. As such, organisations are likely to have a distinct unitary culture, but this culture could be more or less adaptive and receptive to alternative approaches, based on the organisation's specific knowledge context – or the combination of expertise of its workforce. This means that firms who fuse creative arts and STEM skills, either by employing individuals who are themselves fused or by employing a range of specialists, may find they have the resources and routines to overcome the challenges of working with organisations with different approaches to learning because such capabilities have already been developed to manage knowledge integration within the firm itself.

A key question set out at the beginning of this thesis was whether skills fusion in the creative industries was being supported by i) individuals who were fused, ii) firms who were fused by employing a range of specialists, or iii) projects that were fused by firms from one knowledge base working alongside firms from a different knowledge base. The thesis finds that all of these types of fusion are taking place, but also that specialisation plays an important role in harnessing the benefits of fusion and vice versa. Firms benefit from a diversity of skills. However, this does not simply mean they would benefit most from all their employees being fused. Instead, firms require a heterogeneity of knowledge contexts, some fused and some specialist workers. Moreover, while firms who combine creative arts and STEM skills in their work are likely to be highly innovative (Sapsed et al., 2013; Siepel et al., 2016, 2019), further innovation can arise through collaboration with other organisations from a different knowledge base. In other words, specialisation at the firm level can also contribute to innovation through fusion with other specialised firms.

Consequently, the findings of this thesis suggest there should not be a one size fits all approach to fusion. Both fusion and specialisation are important for innovation, as without specialisation there would be nothing to fuse. For the creative industries to prosper, they require heterogeneity of knowledge contexts. They need both fused and specialist individuals working together in fused and specialist firms.

5.2.3. What do the findings of the thesis tell us about fusion? - introducing knowledge liminality

So what do these findings tell us about the nature of fusion? In the introductory chapter of this thesis, fusion was defined as the combination of information and proficiencies (skills) arising from different methods of advancing knowledge (arts and sciences), that are embedded within an individual, group or organisation and embodied through action. However, the findings of the thesis suggest that emphasis on the 'combination' of skills tells us only half the story. What paper 2 reveals is that combinations are productive for innovation by increasing the repertoire of knowledge from which new ideas can emerge, and therefore increasing the likelihood of "surprising combinations of different, opposing concepts and realities" (Bilton & Leary, 2002, p.57). However, it also reveals how new knowledge is forged in the space between disciplines, the gaps, misunderstandings, and misalignments out of which innovation emerges.

Lester and Piore argue that "ambiguity is the critical resource out of which new ideas emerge. It is ambiguity that makes the conversation worth having, not the exchange of chunks of agreed-upon information" (2009, p.54). Similarly, Nonaka and Toyama argue that new knowledge is created “through the synthesis of contradictions, instead of finding an optimal balance between contradictions” (2003, p.3). It is the misalignment between “viewpoints, potential solutions, and perspectives held by individual team members [...which] facilitates experimentation with novel associations” (Tiwana & Mclean, 2005, p.20). As such, the findings of this thesis point to an understanding of fusion as both the combination of creative arts and STEM skills and the productive space between the two. Consequently, skills fusion can be theorised as a form of ‘knowledge liminality’, something which is neither science nor arts but something which simultaneously encompasses neither and both.

The concept of liminality is primarily associated with the anthropologist Van Gennep (1960 [1909]) and later the work of Turner (1982), who used the phrase to describe a period of ritualistic transition. Turner describes liminality as ‘betwixt and between’ states, a period of “ambiguity and paradox [...] whence novel configurations of ideas and relations may arise” (1982, p.236). Evoking Burt’s (2004) notion of structural holes, which emphasise the productive space between groups within an organisation, liminality depicts the betweenness of things, the concrete something that is neither one thing nor the other.

The concept of liminality has been adopted in recent management research to describe temporary employees (Garsten, 1999), temporary organisations (Tempest & Starkey, 2004) and consultancy activities (Czarniawska & Mazza, 2003). Originally conceived as denoting the often ritualised moment of passage between two states, contemporary organisational theorists have suggested that organisations and employees can also exist within a state of ‘permanent liminality’ (Ellis & Ybema, 2010; Johnsen & Sørensen, 2015; Bamber et al., 2017), not just transitioning from one state to another, but permanently exiting between states. Those in permanent liminality are “boundary bricoleurs who constantly switch their identifications by crossing and drawing lines of demarcation” (Ybema et al., 2011, p.28). Crucially, these liminal spaces are free from the rules and constraints of a fixed state, where ideas, identities and loyalties can be challenged and experimented with. As such, liminal states can be spaces of ‘revolutionary thinking’, of learning, innovation, playfulness and creativity (Söderlund & Borg, 2018).

The notion of liminality is therefore helpful in understanding what skills fusion is and how it operates, by drawing attention to the productiveness of ‘in-betweenness’.

Similarly to the concept of fusion presented in this thesis, the concept of liminality has been applied at the level of the individual, group, or society (Horvath et al., 2015), or more specifically in regards to organisational studies at the level of the individual, organisation and between organisations (Söderlund & Borg, 2018). However, here it is productive to consider liminality in regards to knowledge itself. For individuals, multidisciplinary education creates liminal thought processes and identities (Beech, 2011). Through exposure to differing disciplinary paradigms and cultures, those with a multidisciplinary educational background are no longer able to view the world from a singular perspective, but are able to experiment with differing approaches. They need not conform to strict ideas or identities from one discipline or another and are free to pick apart, combine and recombine from each. For example, Tempest and Starkey, specifically examine liminality in relation to the television industry, finding that multi-skilled workers operating in liminal roles "eroded the creative/technocrat divide in television, thus enabling broader jobs that combine both types of skills" (2004, p.516). As such, conceiving of fusion at the individual level as a liminality of knowledge draws together the themes of disciplinary identity, language, methods and approaches to learning that is explored in paper 1. Moreover, the fused firm can be seen as a liminal entity, creating a space where evaluative principles are in constant flux (Stark, 2011), where there is no 'one way' of doing things, but rather where innovation arises from the productive friction between contrasting viewpoints. This is exemplified in paper 2, where we see how innovation occurs through the gaps between knowledge contexts, though the precise interplay of commonality and diversity. At the inter-firm level too, conceiving of fusion as knowledge liminality provides opportunity to reimagine R&D collaborations as projects which exist neither totally outside nor totally inside the boundaries of the firm. As paper 3 shows, at the inter-firm level, fusion between firms from different industries, or from differing knowledge bases, encompass the very process of creating something out of 'in-betweenness'.

Consequently, synthesising the findings from all three papers in this thesis reveals that fusion acts as a form of knowledge liminality, contributing to innovation at the individual, firm and inter-firm levels by providing a space which is betwixt and between the arts and sciences; where languages, identities, concepts, ideas, approaches and world views collide, compete, meld and merge without the constraints of disciplinary paradigms. It is in this space of in-betweenness, of creativity and playfulness, that novel combinations and recombinations of disparate knowledges emerge. It is the pregnant (non-)space of knowledge liminality in which innovation is born.

5.3. Thesis Contribution

5.3.1. Implications for theory

The findings of this thesis present multiple contributions to theory. Firstly, the thesis as a whole extends our understanding of what skills fusion actually is. The introduction chapter to the thesis sets out a view that skills fusion can be conceived as the combination of information and proficiencies (skills) arising from different methods of advancing knowledge (arts and sciences), that are embedded within an individual, group or organisation and embodied through action. This draws together theories of disciplinary demarcation from education literature and theories of knowledge and learning from organisational studies literature. In doing so, the definition of fusion presented in the thesis contributes a theoretically driven understanding of the distinction between arts and science based disciplines and highlights the inherently social practice of skills fusion, hinting towards the importance of issues of identity, social capital, organisational learning etc. Moreover, the thesis presents the concept of skills fusion as a multi-level construct. Prior work on fusion has tended to focus solely on one level of analysis – the individual, firm or inter-firm. This range of units of analysis largely corresponds to differing empirical and disciplinary contexts and necessitates differing theoretical approaches. However, by bringing together theories of fusion from differing disciplines to examine fusion at each key level of analysis, the thesis contributes a more extensive investigation of the notion of fusion than has previously been achieved. In doing so, it also highlights the intersections between each level of analysis – how skills fusion at the individual level may contribute to fusion at the firm level etc. Thus the thesis both furthers our understanding of how fusion operates and contributes to existing literatures which view the firm from a multi-level perspective.

Secondly, the thesis contributes a major development in our understanding of the role of common and diverse knowledge in fostering innovation. By developing a theoretically driven taxonomy of common/diverse knowledge, the thesis argues that diversity is not something of which there can simply be 'more or less', but rather that different forms of knowledge can be either common or diverse. The thesis also makes the theoretical distinction between component and system level knowledge, which is key to understanding how the benefits of knowledge diversity can be harnessed while mitigating the challenges of diverse team work repeatedly reported in extant literature. In doing so, the thesis presents a robust taxonomy of common/diverse knowledge, extending Carlile's (2002, 2004) framework for assessing knowledge boundaries by applying the notion of syntactic, semantic and pragmatic boundaries to the concept of knowledge itself, and further incorporating Spender's (1996) theorisations of the firm as a system of component parts, to present a framework for assessing syntactic, semantic and pragmatic knowledge at both the component and system levels. Consequently, the novel theoretical framework presented in chapter 3 of this thesis significantly contributes to knowledge integration literatures and offers a useful framework to conceptualise and examine innovation and knowledge integration processes.

5.3.2. Implications for practice

The papers contained in this thesis also offer useful contributions to creative industries practitioners. The thesis finds that, in the context of a highly innovative VFX firm, innovation arises from the gap in knowledge contexts between employees with diverse component level syntactic, semantic and pragmatic knowledge, but that the successful implementation of innovation requires common knowledge at the system level. This finding has clear implications for those wishing to enhance their firm's innovation capabilities.

Firms wishing to improve innovation performance would benefit from hiring policies which explicitly encourage a wide range of skills. In seeking to maximise the skills diversity of the workforce, firms might consider actively recruiting creative arts specialists, STEM specialists and fused trans-specialists in order to extend the range of perspectives available to draw upon in innovation processes. Alongside this, firms could look to extend inhouse training to offer supplementary skills development in areas which employees lack existing knowledge. This may mean, for example, coding courses for artists or life drawing courses for coders (both of which are offered at the case study firm in paper 2). Moreover, these differences in knowledge contexts should not be eradicated by routines and processes which seek to instil consensus, but rather difference and conflicting options should be harnessed. At the same time however, firms should work to communicate clear firm level goals and develop regular communication patterns between all members of the organisation. The 'dailies' referred to in paper 2 are a great example of how regular team meetings, coupled with the use of boundary objects and firm level templates can encourage productive communication while maintaining diverse perspectives.

5.3.3. Implications for policy

The findings of this thesis have clear implications for both skills and innovation policy in the UK. Firstly, the findings of paper 1 demonstrate that the creative industries are being heavily supported by fused individuals, with fused graduates being the largest group in creative industries employment. However, the findings also suggest that current HE practices are hindering opportunity for students to acquire a fused skillset at higher levels of education. The thesis echoes recent recommendations to the European Parliament (Davies & Ward Dyer, 2019), in contending that continued growth of the creative industries requires increased opportunity to study a mix of creative and technological subjects in higher education. If the UK government wants to support the growth of the UK creative industries, it is imperative that they focus education policy on creating the opportunity for students to learn both creative arts and STEM skills throughout their education. Moreover, whilst the Creative Sector Deal acknowledges the need for a "combination of STEM and arts-based subjects" (HM Government, 2018, p.55), education policy in the UK continues to focus almost exclusively on STEM at the exclusion of arts based subjects (e.g. DfE, 2021). As this thesis finds that even a small amount of arts training can increase the likelihood of a graduate finding work in the creative industries, in order to support the sector, education policy should work to dispel the myth that creative arts courses do not offer viable routes to employment.

Additionally, the findings of paper 3 suggest that the government has an important role to play in supporting fusion through its funding of R&D. While the paper finds that creative industries firms are receiving government funding for collaborative R&D, this is not uniform across all creative sectors. For example, the advertising and marketing sector is the third largest subsector of the creative industries and contributes £17.1bn to the UK economy (DCMS, 2021), yet only 12 advertising and marketing firms have been awarded funding from InnovateUK to conduct collaborative R&D projects in the last 16 years. This demonstrates a clear opportunity for innovation policy in the UK to better exploit the skills of sectors which are currently underrepresented in the InnovateUK portfolio, by encouraging applications for collaborative R&D grants from these sectors. Moreover, in order to support more robust innovation systems, innovation policy should look to encourage more fused R&D projects. As the thesis finds that being involved in a fused collaboration project in the past increases the likelihood of being involved in a fused project in the future, a short term, targeted approach to promote fused collaboration could see sustained increases in this type of project in the future. This targeted approach to supporting fused collaboration should also consider how to encourage smaller firms to engage in such projects. Focusing innovation policy towards fused R&D would greatly strengthen the UK's innovation capabilities and promote growth for not only the creative industries, but across innovation ecosystems.

5.3.4. Contribution summary

In summary, this thesis makes a significant original contribution to both conceptual and empirical understandings of how the fusion of creative arts and STEM skills contributes to innovation in and around the UK creative industries. The findings of the thesis can be used to help guide individuals making choices about their education pathways, firms in developing their innovation capabilities, policy makers in supporting the continued growth of the creative sector and researchers interested in advancing knowledge in this area. Moreover, as a mixed methods interdisciplinary thesis, the work itself exemplifies how bridging disciplinary boundaries can lead to novel and fruitful avenues of enquiry.

5.4. Limitations and directions for future research

Despite the overall contributions, there are a number of limitations of the work, which present opportunities for further exploration.

The investigation of fusion at the individual level has been conducted using data from the 2012/13 cohort of UK graduates, as this was the last year in which data was collected on graduate outcomes three years after graduation[19]. It is important therefore to highlight that this data set represents only a snapshot of graduate outcomes and that both the educational landscape and the jobs market for that group will inevitably be different to that for graduates from prior and subsequent cohorts. As such, future work could look to conduct similar analysis using a longitudinal dataset to ascertain whether we see similar patterns across years and the extent to which fusion may be growing or declining.

Moreover, limited by data availability, the analysis only considers fusion at the individual level as it relates to formal qualifications taken through traditional education pathways and does not incorporate analysis of alternative education and learning such as apprenticeships, extracurricular or non-formally assessed education, commercial

[19] The DLHE Long survey which was conducted three years after graduation and the DLHE survey which was conducted six months after graduation were replaced by the Graduate Outcomes survey, which gather similar data in a single survey conducted fifteen months after graduation.

training schemes, or on-the-job training. There are of course myriad ways in which individuals can acquire new skills and consideration of additional routes to learning in assessing skills fusion at the individual level would help to strengthen research in this area.

In relation to the thesis' examination of fusion at the firm level, paper 2 relied on a single case study design. While this methodology enabled in-depth analysis that aided in theory building, there remain limitations to the generalisability of the specific findings. As such, future work could look to apply the theory developed in the paper to other types of firms, for example firms in different industries or of different sizes, to assess whether the same combinations of common and diverse knowledge types support innovation and knowledge integration across contexts.

There are limitations too in the investigation of fusion at the inter-firm level. Paper 3 used data from InnovateUK and as such purposely only captured publicly funded R&D collaborations. There will undoubtedly be many more inter-firm collaborations between creative industries and non-creative industries partners that are not captured in this dataset. As such, the analysis conducted in this thesis would be greatly complemented by work which was able to assess privately funded and/or less formal inter-industry collaborations.

Moreover, investigation of the InnovateUK data in this thesis remains primarily exploratory. In order to more fully understand the extent to which fusion at the inter-firm level is beneficial for innovation, it would be pertinent to link this dataset to measures of project success, such as patent and copyright filing, firm level growth metrics, and/or measures of product uptake/diffusion.

In addition, both paper 1 and paper 3 rely on large datasets to ascertain patterns in the prevalence of fusion at the individual and inter-firm levels, respectively. As such, they are limited to explicating the pervasiveness of fusion at the individual and inter-firm levels, rather than assessing causality between such fusion and innovation directly. While the findings of this thesis help to explain how fusion at the individual and inter-firm levels can support fusion at the firm level, which has been directly linked to innovation and firm growth (Sapsed et al., 2013; Siepel et al., 2016, 2019), future work could look to evidence this more thoroughly, with extended investigation of a causal link between fusion and innovation at the individual and inter-firm levels.

Furthermore, both papers 1 and 3 are limited in their ability to speak in-depth about many of the issues related to skills fusion such as identity, communication, values motivations etc. Thus, the work presented here would be greatly complimented by extended qualitative analysis which considers the experiences of those who have a fused educational background, and the experiences of those involved in fused R&D collaborations.

In relation to linking the overall framework of the thesis to the operationalisation of fusion as a multilevel construct in each of the three papers, it is also worth mentioning the lack of data on freelance workers. It is well known that freelance work pays a large role in creative industries economies (Easton & Cauldwell-French, 2017; Henry et al., 2021), and future work could look to further investigate the role of freelancers in contributing to skills fusion. For example the extent to which freelancers are more likely to have fused skills at the individual level, the extent to which freelancers contribute to knowledge integration processes at the firm level and the extent to which freelancers act as knowledge brokers in fused inter-firm collaborations.

It is also important to point out that, whilst the thesis makes a significant original contribution to understanding creative arts and STEM fusion in the UK, much could be learned about the nature of fusion by conducting research in different geographical contexts. For example, how does the UK education system compare to education in other parts of the world in regards to fused skills provision? To what extent are arts and sciences viewed as oppositional fields in other educational and work cultures? What policies have been implemented in other countries to support fused collaborations and R&D that could be adopted by a UK government? Cross-country comparative analysis of each of these issues and more could greatly aid in distinguishing what is consistent in the link between skills fusion and innovation and what is context specific, and could aid in the development of both education and innovation policy in the UK.

As a final note, it would be remiss not to mention the impact of the Covid-19 pandemic on the creative industries, both in the UK and across the globe. Data collection and analysis for this thesis were conducted before the pandemic took hold and therefore could be argued to speak to a very different world to that within which we find ourselves in 2021. Although many creative firms thrived during the various lockdown measures that the UK endured, this was not uniform across creative sectors, with subsectors such as music, visual and performing arts, film, TV, radio and photography and publishing being particularly hard hit (Siepel et al., 2021). However, many creative firms survived this period by using novel technologies and digital mediums to reach new audiences (Creative UK Group, 2021) and there is evidence to suggest that creative companies which fuse their creativity with technology actually saw an increase in investment during

2020 (Creative Industries Council, 2021). This indicates that skills fusion could be a key way in which creative sectors can recover from the economic and social shock of the pandemic. Future research could look to examine this in greater detail by assessing the extent to which skills fusion contributed to firm resilience over the pandemic and the extent to which firms became more fused as a result of shifting business models over this period. Moreover, with government plans to 'build back better' by investing more in creative industries R&D (HM Treasury, 2021), yet simultaneously proposing funding cuts to creative arts subjects in HE (Williamson, 2021), future work could look to track the extent to which the pandemic has acted as a catalyst or hindrance to fusion at the individual, firm and interfirm levels.

5.5. Concluding remarks

It is a prominent contemporary paradigm to argue that modern economies are increasingly reliant upon STEM sectors that require an abundance of STEM skilled employees (Blackley & Howell, 2015). This has influenced policy level decisions that have prioritised STEM education and targeted innovation policy towards only some sectors of the economy. However, with the creative industries being one of the fastest growing sectors of the UK economy, the need for creative skills has perhaps never been higher.

This thesis has demonstrated that the creative industries rely on both creative arts and STEM skills and that it is the distinct combination of these skillsets which fosters innovation in the sector. If policy makers and practitioners wish to support the incredible growth of the creative industries that we have witnessed over the past decade, greater steps must be taken to dismantle disciplinary boundaries, both in the education system and in the workplace, and to promote fusion in all its forms. By embracing the dissonance of colliding and competing knowledge contexts enabled by fusion, actors can transform the 'gulf of mutual incomprehension' of which Snow spoke in the late 1950's, into liminal spaces of creativity and innovation.

6. References

Adams, D. & Fuchs, M. (1985) 'The Fusion of Artistic and Scientific Thinking'. *Art Education*. 38(6). National Art Education Association: pp.22–24.

Adenfelt, M. & Maaninen-Olsson, E. (2007) 'Knowledge Integration Across Projects - Exploring the Role of Boundary Crossing Activities'. *Proceedings of the International Conference on Organizational Knowledge, Learning and Capabilities (OKLC) 2007.*: pp.1–18.

Ahuja, M.K. & Sinclair, R.F. (2012) 'The Influence of Outsourcing Models on Vendor Knowledge Integration'. *JITTA: Journal of Information Technology Theory and Application*. 13(4). Hong Kong, United States: Association for Information Systems: pp.5–19.

Almus, M. & Czarnitzki, D. (2003) 'The Effects of Public R&D Subsidies on Firms' Innovation Activities'. *Journal of Business & Economic Statistics*. 21(2). Taylor & Francis: pp.226–236.

America for the Arts (2004) *The Definition of the Creative Industries: The Standard Industrial Classification (SIC) Codes of the Nation's Arts-Related Businesses*. America for the Arts.

Ancona, D.G. & Caldwell, D.F. (1992) 'Demography and Design: Predictors of New Product Team Performance'. *Organization Science*. 3(3): pp.321–341.

Argote, L., McEvily, B. & Reagans, R. (2003) 'Managing Knowledge in Organizations: An Integrative Framework and Review of Emerging Themes'. *Management Science*. 49(4): pp.571–582.

Asheim, B. (2007) 'Differentiated knowledge bases and varieties of regional innovation systems'. *Innovation: The European Journal of Social Science Research*. 20(3): pp.223–241.

Asheim, B., Boschma, R. & Cooke, P. (2011) 'Constructing Regional Advantage: Platform Policies Based on Related Variety and Differentiated Knowledge Bases'. *Regional Studies*. 45(7): pp.893–904.

Asheim, B., Grillitsch, M. & Trippl, M. (2017) 'Introduction: Combinatorial Knowledge Bases, Regional Innovation, and Development Dynamics'. *Economic Geography*. 93(5): pp.429–435.

Attewell, P. (1990) 'What is Skill?'. *Work and Occupations*. 17(4): pp.422–448.

Augar, P. (2019) *Independent panel report to the Review of Post-18 Education and Funding*. CP 117. London: Her Majesty's Stationery Office.

Bakhshi, H. (2017) Digital Research and Development in the Arts. In: Ateca-Amestoy, V.M., Ginsburgh, V., Mazza, I., O'Hagan, J., and Prieto-Rodriguez, J. (eds) *Enhancing Participation in the Arts in the EU*. Cham: Springer, pp. 269–280.

Bakhshi, H. & McVittie, E. (2009) 'Creative supply-chain linkages and innovation: Do the creative industries stimulate business innovation in the wider economy?'. *Innovation: Organization & Management*. 11(2): pp.169–189.

Bakhshi, H. & Spilsbury, M. (2019) *The Migrant and Skills Needs of Creative Businesses in the United Kingdom*. London: The Creative Industries Policy and Evidence Centre.

Bakhshi, H. & Windsor, G. (2015) *The Creative Economy and the Future of Employment*. London: Nesta.

Bakhshi, H., Freeman, A. & Desai, R. (2010) *Not rocket science: A roadmap for arts and cultural R&D*. Munich Personal RePEc Archive 52710.

Bakhshi, H., Freeman, A. & Higgs, P.L. (2012) *A dynamic mapping of the UK's creative industries*. London: Nesta.

Bakhshi, H., Hargreaves, I. & Mateos-Garcia, J. (2013) *A manifesto for the creative economy*. London: Nesta.

Bakhshi, H., Djumalieva, J. & Easton, E. (2019) *The Creative Digital Skills Revolution*. London: The Creative Industries Policy and Evidence Centre.

Bamber, M., Allen-Collinson, J. & McCormack, J. (2017) 'Occupational limbo, transitional liminality and permanent liminality: New conceptual distinctions'. *Human Relations*. 70(12). SAGE Publications Ltd: pp.1514–1537.

Banks, M. & Hesmondhalgh, D. (2009) 'Looking for work in creative industries policy'. *International Journal of Cultural Policy*. 15(4): pp.415–430.

Banks, M. & Oakley, K. (2016) 'The dance goes on forever? Art schools, class and UK higher education'. *International Journal of Cultural Policy*. 22(1): pp.41–57.

Bantel, K.A. & Jackson, S.E. (1989) 'Top Management and Innovations in Banking: Does the Composition of the Top Team Make a Difference?'. *Strategic Management Journal*. 10: pp.107–124.

Baxter, P. & Jack, S. (2008) 'Qualitative Case Study Methodology: Study Design and Implementation for Novice Researchers'. *The Qualitative Report*. 13(4): pp.18.

Bazalgette, P. (2017) *Independent Review of the Creative Industries*. London: The Department for Culture Media and Sport.

Bechky, B.A. (2003) 'Sharing Meaning Across Occupational Communities: The Transformation of Understanding on a Production Floor'. *Organization Science*. 14(3): pp.312–330.

Beck, J. & Bishop, R. (2018) 'The Return of the Art and Technology Lab'. *Cultural Politics*. 14(2).

Becker, G.S. (2009) *Human Capital: A Theoretical and Empirical Analysis, with Special Reference to Education*. Chicago, IL.: University of Chicago Press.

Becker, M.C. (2004) 'Organizational routines: a review of the literature'. *Industrial and Corporate Change*. 13(4): pp.643–678.

Becker, M.C. & Zirpoli, F. (2003) 'Organizing new product development: Knowledge hollowing-out and knowledge integration – the FIAT Auto case'. *International Journal of Operations & Production Management*. 23(9): pp.1033–1061.

Beech, N. (2011) 'Liminality and the practices of identity reconstruction'. *Human Relations*. 64(2). SAGE Publications Ltd: pp.285–302.

Belderbos, R., Gilsing, V., Lokshin, B., Carree, M. & Fernández Sastre, J. (2018) 'The antecedents of new R&D collaborations with different partner types: On the dynamics of past R&D collaboration and innovative performance'. *Long Range Planning*. 51(2): pp.285–302.

Bequette, J.W. & Bequette, M.B. (2012) 'A Place for Art and Design Education in the STEM Conversation'. *Art Education*. 65(2): pp.40–47.

Berggren, C., Bergek, A., Bengtsson, L. & Söderlund, J. (2011) Exploring Knowledge Integration and Innovation. In: Berggren, C., Bergek, A., Bengtsson, L., Hobday, M., and Söderlund, J. (eds) *Knowledge Integration and Innovation: Critical Challenges Facing International Technology-Based Firms*. Oxford: Oxford University Press, pp. 20–58.

Berggren, C., Sydow, J. & Tell, F. (2017) Relating knowledge integration and absorptive capacity: Knowledge boundaries and reflective agency in path-dependent processes. In: Tell, F., Berggren, C., Brusoni, S., and van de Ven, A.H. (eds) *Managing Knowledge Integration Across Boundaries*. Oxford: Oxford University Press.

Bernstein, B. (2000) *Pedagogy, Symbolic Control, and Identity: Theory, Research, Critique*. Revised. Lanham, MD: Rowman & Littlefield.

Bhandar, M. (2008) *Knowledge Clusters: Dealing with a Multilevel Phenomenon*. ID 1601050, SSRN Scholarly Paper, 1 November. Rochester, NY: Social Science Research Network.

Bhandar, M. (2010) 'A Framework for Knowledge Integration and Social Capital in Collaborative Projects'. *Electronic Journal of Knowledge Management*. 8(3): pp.267–280.

Bhandar, M., Pan, S.-L. & Tan, B.C.Y. (2007) 'Towards understanding the roles of social capital in knowledge integration: A case study of a collaborative information systems project'. *Journal of the American Society for Information Science and Technology*. 58(2): pp.263–274.

Bibby, D., Buscha, F., Cerqua, A., Thomson, D. & Urwin, P. (2014) *Estimation of the labour market returns to qualifications gained in English Further Education*. BIS Research Paper 195. London: The Department for Business Innovation and Skills.

Biglan, A. (1973a) 'Relationships between subject matter characteristics and the structure and output of university departments.'. *Journal of Applied Psychology*. 57(3): pp.204–213.

Biglan, A. (1973b) 'The characteristics of subject matter in different academic areas.'. *Journal of Applied Psychology*. 57(3): pp.195–203.

Bilton, C. & Leary, R. (2002) 'What can managers do for creativity? Brokering creativity in the creative industries'. *International Journal of Cultural Policy*. 8(1): pp.49–64.

Bird, G., Gorry, H., Roper, S. & Love, J. (2020) *R&D in Creative Industries Survey – 2020*. London: The Department for Culture Media and Sport.

Bjerregaard, T. (2010) 'Industry and academia in convergence: Micro-institutional dimensions of R&D collaboration'. *Technovation*. 30(2): pp.100–108.

Blackley, S. & Howell, J. (2015) 'A STEM Narrative: 15 Years in the Making.'. *Australian Journal of Teacher Education*. 40(40).

Blair, A. & Grafton, A. (1992) 'Reassessing Humanism and Science'. *Journal of the History of Ideas*. 53(4). University of Pennsylvania Press: pp.535–540.

Blatchford, I. & Blyth, T. (2019) *The Art of Innovation: From Enlightenment to Dark Matter*. London: Random House.

Bloom, M. (2020) *For Love or Money? Graduate Motivations and the Economic Returns of Creative Higher Education Inside and Outside the Creative Industries*. London: The Creative Industries Policy and Evidence Centre.

Bloom, M. & Bakhshi, H. (2020) *Graduate Motivations and the Economic Returns of Creative Higher Education Inside and Outside the Creative Industries*. Insights for Policymakers. London: The Creative Industries Policy and Evidence Centre.

Boari, C. & Riboldazzi, F. (2014) 'How knowledge brokers emerge and evolve: The role of actors' behaviour'. *Research Policy*. 43(4): pp.683–695.

Boltanski, L. & Thévenot, L. (2006) *On Justification: Economies of Worth*. Princeton, NJ.: Princeton University Press.

BOP Consulting (2010) *Mapping the Creative Industries: A Toolkit*. London: British Council.

Borrego, M. & Newswander, L.K. (2010) 'Definitions of Interdisciplinary Research: Toward Graduate-Level Interdisciplinary Learning Outcomes'. *The Review of Higher Education*. 34(1): pp.61–84.

Boschma, R. (2005) 'Proximity and Innovation: A Critical Assessment'. *Regional Studies*. 39(1): pp.61–74.

Boschma, R. (2018) A Concise History of the Knowledge Base Literature: Challenging Questions for Future Research. In: Isaksen, A., Martin, R., and Trippl, M. (eds) *New Avenues for Regional Innovation Systems - Theoretical Advances, Empirical Cases and Policy Lessons*. Cham: Springer International Publishing, pp. 23–40.

Bracken (Née Bull), L.J. & Oughton, E.A. (2006) ''What Do You Mean?' The Importance of Language in Developing Interdisciplinary Research'. *Transactions of the Institute of British Geographers*. 31(3): pp.371–382.

Breschi, S., Lissoni, F. & Malerba, F. (2003) 'Knowledge-relatedness in firm technological diversification'. *Research Policy*. 32(1): pp.69–87.

Broekel, T., Brachert, M., Duschl, M. & Brenner, T. (2017) 'Joint R&D Subsidies, Related Variety, and Regional Innovation'. *International Regional Science Review*. 40(3): pp.297–326.

Brown, A., O'Connor, J. & Cohen, S. (2000) 'Local music policies within a global music industry: cultural quarters in Manchester and Sheffield'. *Geoforum*. 31(4): pp.437–451.

Brown, J.S., Collins, A. & Duguid, P. (1989) 'Situated Cognition and the Culture of Learning'. *Educational Researcher*. 18(1): pp.32–42.

Brun, E., Sætre, A.S. & Gjelsvik, M. (2008) 'Benefits of Ambiguity in New Product Development'. *International Journal of Innovation and Technology Management*. 5(3): pp.303–319.

Brunow, S., Birkeneder, A. & Rodríguez-Pose, A. (2018) 'Creative and science oriented employees and firm-level innovation'. *Cities*. 78: pp.27–38.

Brusoni, S., Prencipe, A. & Pavitt, K. (2001) 'Knowledge Specialization, Organizational Coupling, and the Boundaries of the Firm: Why Do Firms Know More Than They Make?'. *Administrative Science Quarterly*. 46(4): pp.597–621.

Bullot, N.J., Seeley, W.P. & Davies, S. (2017) 'Art and Science: A Philosophical Sketch of Their Historical Complexity and Codependence'. *The Journal of Aesthetics and Art Criticism*. 75(4): pp.453–463.

Burt, R.S. (2004) 'Structural Holes and Good Ideas'. *American Journal of Sociology*. 110(2). The University of Chicago Press: pp.349–399.

Campbell, D.J. (1988) 'Task Complexity: A Review and Analysis'. *Academy of Management Review*. 13(1): pp.40–52.

Campbell, P., O'Brien, D. & Taylor, M. (2019) 'Cultural Engagement and the Economic Performance of the Cultural and Creative Industries: An Occupational Critique'. *Sociology*. 53(2). SAGE Publications Ltd: pp.347–367.

Carlile, P.R. (2002) 'A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development'. *Organization Science*. 13(4): pp.442–455.

Carlile, P.R. (2004) 'Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge across Boundaries'. *Organization Science*. 15(5): pp.555–568.

Carlile, P.R. & Rebentisch, E.S. (2003) 'Into the Black Box: The Knowledge Transformation Cycle'. *Management Science*. 49(9): pp.1180–1195.

Carter, C.R., Meschnig, G. & Kaufmann, L. (2015) 'Moving to the Next Level: Why Our Discipline Needs More Multilevel Theorization'. *Journal of Supply Chain Management*. 51(4): pp.94–102.

Caves, R.E. (2000) *Creative Industries: Contracts Between Art and Commerce*. Cambridge, MA.: Harvard University Press.

Chapain, C. & Stachowiak, K. (2017) The governance of innovation in the Film and Television industry: a case study of London, UK. In: Chapain, C. and Stryjakiewicz, T. (eds) *Creative Industries in Europe*. Cham: Springer International Publishing, pp. 65–94.

Chapain, C., Cooke, P., De Propris, L., MacNeill, S. & Mateos-Garcia, J. (2010) *Creative Clusters and Innovation: Putting Creativity on the Map*. London: Nesta.

Chettiparamb, A. (2007) *Interdisciplinarity: a literature review*. 1 November. Southampton: The Higher Education Academy: Interdisciplinary Teaching and Learning Group.

Christopherson, S. & Clark, J. (2007) *Remaking Regional Economies: Power, Labor, and Firm Strategies in the Knowledge Economy*. London: Routledge.

Christopherson, S. & Storper, M. (1986) 'The City as Studio; The World as Back Lot: The Impact of Vertical Disintegration on the Location of the Motion Picture Industry'. *Environment and Planning D: Society and Space*. 4(3): pp.305–320.

Cohen, W.M. & Levinthal, D.A. (1990) 'Absorptive Capacity: A New Perspective on Learning and Innovation'. *Administrative Science Quarterly*. 35(1): pp.128–152.

Colapinto, C. & Porlezza, C. (2012) 'Innovation in Creative Industries: from the Quadruple Helix Model to the Systems Theory'. *Journal of the Knowledge Economy*. 3(4): pp.343–353.

Collins, C.J. & Smith, K.G. (2006) 'Knowledge Exchange and Combination: The Role of Human Resource Practices in the Performance of High-Technology Firms'. *The Academy of Management Journal*. 49(3): pp.544–560.

Colucci-Gray, L., Burnard, P., Cooke, C., Davies, R., Gray, D. & Trowsdale, J. (2017) *Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning*. London: British Educational Research Association.

Colucci-Gray, L., Burnard, P., Gray, D. & Cooke, C. (2019) A Critical Review of STEAM (Science, Technology, Engineering, Arts, and Mathematics). In: *Oxford Research Encyclopedia of Education*. Oxford: Oxford University Press.

Comunian, R. (2009) 'Questioning creative work as driver of economic development: the case of Newcastle-Gateshead'. *Creative Industries Journal*. 2(1): pp.57–71.

Comunian, R., Faggian, A. & Jewell, S. (2011) 'Winning and losing in the creative industries: an analysis of creative graduates' career opportunities across creative disciplines'. *Cultural Trends*. 20(3–4): pp.291–308.

Comunian, R., Faggian, A. & Jewell, S. (2014) 'Embedding Arts and Humanities in the Creative Economy: The Role of Graduates in the UK'. *Environment and Planning C: Government and Policy*. 32(3): pp.426–450.

Comunian, R., Faggian, A. & Jewell, S. (2015) 'Digital technology and creative arts career patterns in the UK creative economy'. *Journal of Education and Work*. 28(4): pp.346–368.

Converse, P.D., Oswald, F.L., Gillespie, M.A., Field, K.A. & Bizot, E.B. (2004) 'Matching Individuals to Occupations Using Abilities and the O*net'. *Personnel Psychology*. 57(2): pp.451–487.

Cook, S.D.N. & Brown, J.S. (1999) 'Bridging Epistemologies: The Generative Dance between Organizational Knowledge and Organizational Knowing'. *Organization Science*. 10(4): pp.381–400.

Cooke, P. & De Propris, L. (2011) 'A policy agenda for EU smart growth: the role of creative and cultural industries'. *Policy Studies*. 32(4): pp.365–375.

Creative Industries Council (2014) **Create UK: Creative industries strategy*. London: Creative Industries Council UK.

Creative Industries Council (2021) *The CreaTech Report 2021*.

Creative Industries Federation (2016) *Social Mobility and the Skills Gap: Creative Education Agenda 2016*. London: Creative Industries Federation.

Creative Skillset (2014) *Creative Media Workforce Survey 2014*. London: Creative Skillset.

Creative UK Group (2021) *The UK Creative Industries: Unleashing the power and potential of creativity*.

Cultural Learning Alliance (2017) *STEAM: Why STEM can only take us so far*. Cultural Learning Alliance Briefing Paper No. 1. Cultural Learning Alliance.

Currall, S.C. & Inkpen, A.C. (2002) 'A Multilevel Approach to Trust in Joint Ventures'. *Journal of International Business Studies*. 33(3): pp.479–495.

Curtin, M. (2016) 'Regulating the global infrastructure of film labor exploitation'. *International Journal of Cultural Policy*. 22(5): pp.673–685.

Curtin, M. & Vanderhoef, J. (2015) 'A Vanishing Piece of the Pi: The Globalization of Visual Effects Labor'. *Television & New Media*. 16(3): pp.219–239.

Czarniawska, B. & Mazza, C. (2003) 'Consulting as a Liminal Space'. *Human Relations*. 56(3): pp.267–290.

Czarnitzki, D., Ebersberger, B. & Fier, A. (2007) 'The relationship between R&D collaboration, subsidies and R&D performance: Empirical evidence from Finland and Germany'. *Journal of Applied Econometrics*. 22(7): pp.1347–1366.

D'Adderio, L. (2001) 'Crafting the virtual prototype: how firms integrate knowledge and capabilities across organisational boundaries'. *Research Policy*. 30(9). Codification of Knowledge: pp.1409–1424.

Darbellay, F. (2015) 'Rethinking inter- and transdisciplinarity: Undisciplined knowledge and the emergence of a new thought style'. *Futures*. 65: pp.163–174.

Daskalaki, M. (2010) 'Building 'Bonds' and 'Bridges': Linking Tie Evolution and Network Identity in the Creative Industries'. *Organization Studies*. 31(12): pp.1649–1666.

Dass, M., Goodwin, A., Wood, M. & Ni Luanaigh, A. (2015) *Sector insights: skills and performance challenges in the digital and creative sector: June 2015*. UK Commission for Employment and Skills Evidence Report 92.

Daugherty, M.K. (2013) 'The Prospect of an "A" in STEM Education'. *Journal of STEM Education*. 14(2): pp.10–15.

Davies, J. & Ward Dyer, G. (2019) *The relationship between artistic activities and digital technology development*. PE 634.440. Brussels: Panel for the Future of Science and Technology, European Parliament.

Davis, C.H., Creutzberg, T. & Arthurs, D. (2009) 'Applying an innovation cluster framework to a creative industry: The case of screen-based media in Ontario'. *Innovation: Management, Policy & Practice*. 11(2): pp.201–214.

DCMS (2001) *Creative industries mapping document 2001*. London: The Department for Culture Media and Sport.

DCMS (2008) *Creative Britain: New Talents for the New Economy*. London: The Department for Culture Media and Sport.

DCMS (2016) *Creative Industries Economic Estimates Methodology*. London: The Department for Culture Media and Sport.

DCMS (2019a) *DCMS Sectors Economic Estimates 2017: GVA*. January. London: The Department for Culture Media and Sport.

DCMS (2019b) *DCMS Sectors Economic Estimates 2018: Employment*. London: The Department for Culture Media and Sport.

DCMS (2020) *DCMS Sectors Economic Estimates 2018: GVA (provisional)*. London: The Department for Culture Media and Sport.

DCMS (2021) *Tables 1-8: GVA of DCMS Sectors and subsectors, 2010 - 2019*. London: The Department for Culture Media and Sport.

DeFillippi, R. (2015) Managing project-based organization in creative industries. In: Jones, C., Lorenzen, M., and Sapsed, J. (eds) *The Oxford Handbook of Creative Industries*. Oxford University Press, pp. 268–283.

Demsetz, H. (1988) 'The Theory of the Firm Revisited'. *Journal of Law, Economics, & Organization*. 4(1): pp.141–161.

D'Este, P. & Patel, P. (2007) 'University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry?'. *Research Policy*. 36(9): pp.1295–1313.

DfE (2019) *Graduate outcomes (LEO): Employment and earnings outcomes of higher education graduates by subject studied and graduate characteristics in 2016/17*. London: The Department for Education.

DfE (2021) *Skills for Jobs: Lifelong Learning for Opportunity and Growth*. London: The Department for Education.

Dibiaggio, L. (2007) 'Design complexity, vertical disintegration and knowledge organization in the semiconductor industry'. *Industrial and Corporate Change*. 16(2): pp.239–267.

Dibiaggio, L. & Nasiriyar, M. (2009) 'Knowledge integration and vertical specialization in the semiconductor industry'. *European Management Review*. 6(4): pp.265–276.

Docherty, D. (2010) *The Fuse: Igniting High Growth for Creative, Digital and Information Technology Industries in the UK*. London: Council for Industry and Higher Education.

Dosi, G., Nelson, R.R. & Winter, S. (2001) Introduction: The Nature and Dynamics of Organizational Capabilities. In: Dosi, G., Nelson, R.R., and Winter, S. (eds) *The Nature and Dynamics of Organizational Capabilities*. Oxford: Oxford University Press, pp. 1–24.

Dougherty, D. (1992) 'Interpretive Barriers to Successful Product Innovation in Large Firms'. *Organization Science*. 3(2): pp.179–202.

Easton, E. & Cauldwell-French, E. (2017) *Creative Freelancers*. London: The Creative Industries Federation.

Edmondson, A.C. & Harvey, J.-F. (2018) 'Cross-boundary teaming for innovation: Integrating research on teams and knowledge in organizations'. *Human Resource Management Review*. 28(4): pp.347–360.

Eisenhardt, K.M. (1989) 'Building Theories from Case Study Research'. *The Academy of Management Review*. 14(4): pp.532–550.

Eisenhardt, K.M. & Schoonhoven, C.B. (1996) 'Resource-based View of Strategic Alliance Formation: Strategic and Social Effects in Entrepreneurial Firms'. *Organization Science*. 7(2). INFORMS: pp.136–150.

Ellis, N. & Ybema, S. (2010) 'Marketing Identities: Shifting Circles of Identification in Inter-organizational Relationships'. *Organization Studies*. 31(3). SAGE Publications Ltd: pp.279–305.

Enberg, C., Lindkvist, L. & Tell, F. (2006) 'Exploring the Dynamics of Knowledge Integration: Acting and Interacting in Project Teams'. Renzl, B., Matzler, K., and Hinterhuber, H. (eds) *Management Learning*. 37(2): pp.143–165.

Enberg, C., Lindkvist, L. & Tell, F. (2010) 'Knowledge integration at the edge of technology: On teamwork and complexity in new turbine development'. *International Journal of Project Management*. 28(8): pp.756–765.

England, P. (1992) *Comparable Worth: Theories and Evidence*. New York, NY: Springer-Verlag Berlin Heidelberg.

Erkelens, R., van den Hooff, B., Vlaar, P. & Huysman, M. (2010) Knowledge Integration in Global R&D Networks. In: *Global Sourcing of Information Technology and Business Processes: 4th International Workshop, Global Sourcing 2010, Zermatt, Switzerland, March 22-25, 2010, Revised Selected Papers* (eds I. Oshri and J. Kotlarsky), 2010, pp. 82–102.

ESCO (2020) Skills pillar. Available: https://ec.europa.eu/esco/portal/escopedia/Skills_pillar.

Etzkowitz, H. & Leydesdorff, L. (2000) 'The dynamics of innovation: from National Systems and “Mode 2” to a Triple Helix of university–industry–government relations'. *Research Policy*. 29(2): pp.109–123.

Ewenstein, B. & Whyte, J. (2009) 'Knowledge Practices in Design: The Role of Visual Representations as `Epistemic Objects''. *Organization Studies*. 30(1): pp.07–30.

Faggian, A., Comunian, R., Jewell, S. & Kelly, U. (2013) 'Bohemian Graduates in the UK: Disciplines and Location Determinants of Creative Careers'. *Regional Studies*. 47(2): pp.183–200.

FAME (2021) Framestore limited company report. Bureau van Dijk. Available: http://fame.bvdep.com.

Fang, E. (Er), Palmatier, R.W., Scheer, L.K. & Li, N. (2008) 'Trust at Different Organizational Levels'. *Journal of Marketing*. 72(2). SAGE Publications Inc: pp.80–98.

Fay, D., Borrill, C., Amir, Z., Haward, R. & West, M.A. (2006) 'Getting the most out of multidisciplinary teams: A multi-sample study of team innovation in health care'. *Journal of Occupational and Organizational Psychology*. 79(4): pp.553–567.

Flew, T. (2011) *The Creative Industries: Culture and Policy*. London: SAGE.

Flew, T. (2013) *Global Creative Industries*. Global media and communication. Cambridge, UK: Polity.

Foster, P., Manning, S. & Terkla, D. (2015) 'The Rise of Hollywood East: Regional Film Offices as Intermediaries in Film and Television Production Clusters'. *Regional Studies*. 49(3): pp.433–450.

Frenette, A. & Tepper, S.J. (2016) What difference does it make? Assessing the effects of arts-based training on career pathways. In: Comunian, R. and Gilmore, A. (eds) *Higher Education and the Creative Economy: Beyond the Campus*. Routledge, pp. 115–133.

Frenken, K., Oort, F.V. & Verburg, T. (2007) 'Related Variety, Unrelated Variety and Regional Economic Growth'. *Regional Studies*. 41(5): pp.685–697.

Frey, C.B. & Osborne, M.A. (2017) 'The future of employment: How susceptible are jobs to computerisation?'. *Technological Forecasting and Social Change*. 114: pp.254–280.

Fritsch, M. & Franke, G. (2004) 'Innovation, regional knowledge spillovers and R&D cooperation'. *Research Policy*. 33(2): pp.245–255.

Frost, T.S. & Zhou, C. (2005) 'R&D co-practice and ‘reverse’ knowledge integration in multinational firms'. *Journal of International Business Studies*. 36(6): pp.676–687.

Gantogtokh, O. & Quinlan, K.M. (2017) 'Challenges of designing interdisciplinary postgraduate curricula: case studies of interdisciplinary master’s programmes at a research-intensive UK university'. *Teaching in Higher Education*. 22(5). Routledge: pp.569–586.

Garnham, N. (2005) 'From cultural to creative industries: An analysis of the implications of the "creative industries" approach to arts and media policy making in the United Kingdom'. *International Journal of Cultural Policy*. 11(1): pp.15–29.

Garsten, C. (1999) 'Betwixt and between: Temporary Employees as Liminal Subjects in Flexible Organizations'. *Organization Studies*. 20(4): pp.601–617.

Ghanbari, S. (2015) 'Learning across disciplines: A collective case study of two university programs that integrate the arts with STEM'. *International Journal of Education & the Arts*. 16(7).

Giles, L., Spilsbury, M. & Carey, H. (2020) *Creative Skills Monitor*. London: The Creative Industries Policy and Evidence Centre.

Gioia, D.A., Corley, K.G. & Hamilton, A.L. (2013) 'Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology'. *Organizational Research Methods*. 16(1): pp.15–31.

Grabher, G. (2001) 'Ecologies of Creativity: The Village, the Group, and the Heterarchic Organisation of the British Advertising Industry'. *Environment and Planning A: Economy and Space*. 33(2): pp.351–374.

Grandori, A. (2001) 'Neither Hierarchy nor Identity: Knowledge-Governance Mechanisms and the Theory of the Firm'. *Journal of Management and Governance*. 5(3–4): pp.381–399.

Grant, R.M. (1996a) 'Prospering in Dynamically-competitive Environments: Organizational Capability as Knowledge Integration'. *Organization Science*. 7(4): pp.375–387.

Grant, R.M. (1996b) 'Toward a Knowledge-Based Theory of the Firm'. *Strategic Management Journal*. 17: pp.109–122.

Green, F. (2011) *What is skill? An inter-disciplinary synthesis*. London: Institute of Education, University of London.

Green, L., Miles, I. & Rutter, J. (2007) *Hidden Innovation in the Creative Sectors*. Working Paper, October. London: Nesta.

Grillitsch, M., Schubert, T. & Srholec, M. (2016) *Knowledge diversity and firm growth: Searching for a missing link*. Lund University, CIRCLE-Center for Innovation, Research and Competences in the Learning Economy Working Paper Series 2016/13.

Grillitsch, M., Schubert, T. & Srholec, M. (2019) 'Knowledge base combinations and firm growth'. *Research Policy*. 48(1): pp.234–247.

Gross, J. (2020) *The birth of the creative industries revisited: An oral history of the 1998 DCMS Mapping Document*. London: King's College.

Guile, D. (2006) 'Access, learning and development in the creative and cultural sectors: from 'creative apprenticeship' to 'being apprenticed''. *Journal of Education and Work*. 19(5): pp.433–453.

Gundolf, K., Jaouen, A. & Gast, J. (2018) 'Motives for strategic alliances in cultural and creative industries'. *Creativity and Innovation Management*. 27(2): pp.148–160.

Hagedoorn, J. (2002) 'Inter-firm R&D partnerships: an overview of major trends and patterns since 1960'. *Research Policy*. 31(4): pp.477–492.

Hagedoorn, J., Link, A.N. & Vonortas, N.S. (2000) 'Research partnerships'. *Research Policy*. 29(4): pp.567–586.

Hargadon, A. & Sutton, R.I. (1997) 'Technology Brokering and Innovation in a Product Development Firm'. *Administrative Science Quarterly*. 42(4). [Sage Publications, Inc., Johnson Graduate School of Management, Cornell University]: pp.716–749.

Hargadon, A.B. (1998) 'Firms as Knowledge Brokers: Lessons in Pursuing Continuous Innovation'. *California Management Review*. 40(3). SAGE Publications Inc: pp.209–227.

Hargadon, A.B. (2002) 'Brokering knowledge: Linking learning and innovation'. *Research in Organizational Behavior*. 24: pp.41–85.

Harris, N. (1997) Sohonet: a case study in real-world media networking. In: *IEE Colloquium on ATM in Professional and Consumer Applications (Digest No: 1997/113)*, May 1997, pp. 1–8.

Hecker, A. (2011) 'Specialization, implicit coordination and organizational performance: trading off common and idiosyncratic knowledge'. *Review of Managerial Science*. 5(1): pp.19–47.

HEFCE (2014) *STEM teaching capital funding 2015-16*. Higher Education Funding Council for England.

Hemels, S. (2017) Tax Incentives for the Audio Visual Industry. In: Hemels, S. and Goto, K. (eds) *Tax Incentives for the Creative Industries*. Singapore: Springer, pp. 137–174.

Henry, N., Barker, V., Sissons, P., Broughton, K., Dickinson, P., Lazell, J. & Angus, T. (2021) *Creating Value in Place: Understanding the Role, Contribution and Challenges of Creative Freelance Work*. London: The Creative Industries Policy and Evidence Centre.

HESA (2019) Rounding and suppression to anonymise statistics | HESA. Available: https://www.hesa.ac.uk/about/regulation/data-protection/rounding-and-suppression-anonymise-statistics.

Hesmondhalgh, D. (2018) *The Cultural Industries*. 4th ed. London: SAGE.

Higgs, P., Cunningham, S. & Bakhshi, H. (2008) *Beyond the creative industries: Mapping the creative economy in the United Kingdom*. London: Nesta.

Hitt, M.A., Beamish, P.W., Jackson, S.E. & Mathieu, J.E. (2007) 'Building Theoretical and Empirical Bridges Across Levels: Multilevel Research in Management'. *Academy of Management Journal*. 50(6): pp.1385–1399.

HM Government (2017) *Industrial Strategy: building a Britain fit for the future*. London: The Department for Business Energy and Industrial Strategy.

HM Government (2018) *Industrial Strategy: Creative Industries Sector Deal*. London: The Department for Business Energy and Industrial Strategy.

HM Treasury (2021) *Build Back Better: Our Plan for Growth*.

Hoopes, D.G. & Postrel, S. (1999) 'Shared Knowledge, 'Glitches,' and Product Development Performance'. *Strategic Management Journal*. 20(9): pp.837–865.

Horvath, A., Thomassen, B. & Wydra, H. (2015) *Breaking Boundaries: Varieties of Liminality*. New York, NY.: Berghahn Books.

Horwitz, S.K. & Horwitz, I.B. (2007) 'The Effects of Team Diversity on Team Outcomes: A Meta-Analytic Review of Team Demography'. *Journal of Management*. 33(6): pp.987–1015.

Hottenrott, H. & Lopes-Bento, C. (2014) '(International) R&D collaboration and SMEs: The effectiveness of targeted public R&D support schemes'. *Research Policy*. 43(6): pp.1055–1066.

Huang, J.C. & Newell, S. (2003) 'Knowledge integration processes and dynamics within the context of cross-functional projects'. *International Journal of Project Management*. 21(3): pp.167–176.

Hung, H.-F., Kao, H.-P. & Chu, Y.-Y. (2008) 'An empirical study on knowledge integration, technology innovation and experimental practice'. *Expert Systems with Applications*. 35(1): pp.177–186.

IFF (2017) *Longitudinal Destinations of Leavers from Higher Education 12/13*. London: IFF Research.

Innovate UK (2020) Innovate UK funded projects 2004 to 1 February 2020. Available: https://www.gov.uk/government/publications/innovate-uk-funded-projects.

Jaaniste, L. (2009) 'Placing the creative sector within innovation: The full gamut'. *Innovation*. 11(2): pp.215–229.

Jin, X. & Kotlarsky, J. (2012) 'A Conceptual Framework of Knowledge Integration in Multisourcing Arrangements'. *ICIS 2012 Proceedings*.

Jisun, C. (2010) 'Creative industries and global co-development: Lessons from the first successful case in Korean online games'. *Creative Industries Journal*. 3(2): pp.125–136.

Johnsen, C.G. & Sørensen, B.M. (2015) ''It's capitalism on coke!': From temporary to permanent liminality in organization studies'. *Culture and Organization*. 21(4). Routledge: pp.321–337.

Johnson, H.G. (1960) 'The Political Economy of Opulence'. *The Canadian Journal of Economics and Political Science / Revue canadienne d'Economique et de Science politique*. 26(4): pp.552–564.

Jones, C., Lorenzen, M. & Sapsed, J. (2015) *The Oxford Handbook of Creative Industries*. Oxford University Press.

Kang, K.H. & Kang, J. (2010) 'Does partner type matter in R&D collaboration for product innovation?'. *Technology Analysis & Strategic Management*. 22(8). Routledge: pp.945–959.

KEA European Affairs (2006) *The economy of culture in Europe*. Brussels: European Commission, Director-General for Education and Culture.

King, N. (2012) Doing Template Analysis. In: Symon, G. and Cassell, C. (eds) *Qualitative Organizational Research: Core Methods and Current Challenges*. London: SAGE Publications, Inc., pp. 426–450.

King, N. & Brooks, J.M. (2016) *Template Analysis for Business and Management Students*. London: SAGE.

Kirby, D.A. (2008) Hollywood Knowledge: Communication Between Scientific and Entertainment Cultures. In: Cheng, D., Claessens, M., Gascoigne, T., Metcalfe, J., Schiele, B., and Shi, S. (eds) *Communicating Science in Social Contexts: New Models, New Practices*. Dordrecht: Springer Netherlands, pp. 165–180.

Klein, J.T. (1996) *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities*. Charlottesville, VA.: University of Virginia Press.

Klein, J.T. (2010) A taxonomy of interdisciplinarity. In: Frodeman, R., Klein, J.T., and Mitcham, C. (eds) *The Oxford Handbook of Interdisciplinarity*. Oxford: Oxford University Press, pp. 15–30.

Klein, K.J., Tosi, H. & Cannella, A.A. (1999) 'Introduction to Special Topic Forum: Multilevel Theory Building: Benefits, Barriers, and New Developments'. *The Academy of Management Review*. 24(2). Academy of Management: pp.243–248.

Kogut, B. (1988) 'Joint ventures: Theoretical and empirical perspectives'. *Strategic Management Journal*. 9(4): pp.319–332.

Kogut, B. & Zander, U. (1992) 'Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology'. *Organization Science*. 3(3): pp.383–397.

Kogut, B. & Zander, U. (1996) 'What Firms Do? Coordination, Identity, and Learning'. *Organization Science*. 7(5): pp.502–518.

Květoň, V. & Kadlec, V. (2018) 'Evolution of knowledge bases in European regions: searching for spatial regularities and links with innovation performance'. *European Planning Studies*. 26(7): pp.1366–1388.

La Prade, E. (2002) 'The early days of E.A.T'. *IEEE MultiMedia*. 9(2): pp.4–5.

Lampel, J. & Shamsie, J. (2003) 'Capabilities in Motion: New Organizational Forms and the Reshaping of the Hollywood Movie Industry'. *Journal of Management Studies*. 40(8): pp.2189–2210.

Lampel, J., Lant, T. & Shamsie, J. (2000) 'Balancing Act: Learning from Organizing Practices in Cultural Industries'. *Organization Science*. 11(3): pp.263–269.

Land, M.H. (2013) 'Full STEAM Ahead: The Benefits of Integrating the Arts Into STEM'. *Procedia Computer Science*. 20. Complex Adaptive Systems: pp.547–552.

Lane, P.J. & Lubatkin, M. (1998) 'Relative Absorptive Capacity and Interorganizational Learning'. *Strategic Management Journal*. 19(5): pp.461–477.

Lattuca, L.R., Voight, L.J. & Fath, K.Q. (2004) 'Does interdisciplinarity promote learning? Theoretical support and researchable questions'. *The Review of Higher Education*. 28(1).

Lester, R.K. & Piore, M.J. (2009) *Innovation—The Missing Dimension*. Cambridge, MA.: Harvard University Press.

Lhermitte, M., Perrin, B., Blanc, S., Raufast, V., Alvarez, H., Druesne, J., Echiguer, M., Attias, D., Olivier, B., Melbouci, L., et al. (2015) *Cultural Times The first global map of cultural and creative industries*. Paris: Ernst & Young for Confédération Internationale des Sociétés d'Auteurs et Compositeurs (CISAC).

Lind, F., Styhre, A. & Aaboen, L. (2013) 'Exploring university-industry collaboration in research centres'. *European Journal of Innovation Management*. 16(1): pp.70–91.

Lingo, E.L. & O'Mahony, S. (2010) 'Nexus Work: Brokerage on Creative Projects'. *Administrative Science Quarterly*. 55(1): pp.47–81.

Liu, Y. & Phillips, J.S. (2011) 'Examining the antecedents of knowledge sharing in facilitating team innovativeness from a multilevel perspective'. *International Journal of Information Management*. 31(1): pp.44–52.

Livingstone, I. & Hope, A. (2011) *Next Gen*. London: Nesta.

Loufrani-Fedida, S. & Missonier, S. (2015) 'The project manager cannot be a hero anymore! Understanding critical competencies in project-based organizations from a multilevel approach'. *International Journal of Project Management*. 33(6): pp.1220–1235.

Lyall, C., Meagher, L., Bandola-Gill, J. & Kettle, A. (2015) *Interdisciplinary provision in higher education. Current and future challenges*. 1 January. York: Higher Education Academy.

Mangematin, V., Sapsed, J. & Schüßler, E. (2014) 'Disassembly and reassembly: An introduction to the Special Issue on digital technology and creative industries'. *Technological Forecasting and Social Change*. 83: pp.1–9.

Manniche, J., Moodysson, J. & Testa, S. (2017) 'Combinatorial Knowledge Bases: An Integrative and Dynamic Approach to Innovation Studies'. *Economic Geography*. 93(5): pp.480–499.

Marrone, J.A. (2010) 'Team Boundary Spanning: A Multilevel Review of Past Research and Proposals for the Future'. *Journal of Management*. 36(4): pp.911–940.

Martin, J. (2015) 'A Brief History of Experiments in Art and Technology'. *IEEE Potentials*. 34(6): pp.13–19.

Martínez-Noya, A. & Narula, R. (2018) 'What more can we learn from R&D alliances? A review and research agenda'. *BRQ Business Research Quarterly*. 21(3): pp.195–212.

Mateos-Garcia, J. & Bakhshi, H. (2016) *The Geography of Creativity in the UK*. London: Nesta.

Mathieu, J.E. & Chen, G. (2011) 'The Etiology of the Multilevel Paradigm in Management Research'. *Journal of Management*. 37(2). SAGE Publications Inc: pp.610–641.

Maton, K. (2013) *Knowledge and Knowers: Towards a Realist Sociology of Education*. Abingdon: Routledge.

McAuliffe, M. (2016) 'The Potential Benefits of Divergent Thinking and Metacognitive Skills in STEAM Learning: A discussion paper'. *International Journal of Innovation*. 2(3): pp.13.

McCray, W.P. (2020) *Making Art Work: How Cold War Engineers and Artists Forged a New Creative Culture*. Cambridge, MA.: MIT Press.

McDonald, A. (2016) *FilmL.A. 2016 Feature Film Study*. Hollywood, CA.: FilmL.A.Inc.

McKinlay, A. & Smith, C. (eds) (2009) *Creative Labour: Working in the Creative Industries*. London: Red Globe Press.

Meeth, L.R. (1978) 'Interdisciplinary Studies: A Matter of Definition'. *Change: The Magazine of Higher Learning*. 10(7): pp.10–10.

Mengis, J. (2007) 'Integrating knowledge through communication-the case of experts and decision makers'. *Proceedings of the International Conference on Organizational Knowledge, Learning and Capabilities (OKLC) 2007.*: pp.699–720.

Mengis, J., Nicolini, D. & Swan, J. (2009) 'Working together in the space between expertise and ignorance'. *Proceedings of the International Conference on Organizational Knowledge, Learning and Capabilities (OKLC) 2008*.

Meyer, J.H.F. & Land, R. (2003) Threshold concepts and troublesome knowledge: linkages to ways of thinking and practicing. In: *Improving Student Learning - Ten Years On: Proceedings of the 2002 10th International Symposium Improving Student Learning*, Oxford, 2003. Oxford Centre for Staff & Learning Development.

Miles, I. & Green, L. (2008) *Hidden innovation in the creative industries*. London: Nesta.

Mill, J.S. (2000) *Principles of Political Economy*. Kitchener, Ontario: Batoche Books.

Milliken, F.J. & Martins, L.L. (1996) 'Searching for Common Threads: Understanding the Multiple Effects of Diversity in Organizational Groups'. *The Academy of Management Review*. 21(2): pp.402–433.

Mincer, J. (1958) 'Investment in Human Capital and Personal Income Distribution'. *Journal of Political Economy*. 66(4): pp.281–302.

Molina-Azorín, J.F., Pereira-Moliner, J., López-Gamero, M.D., Pertusa-Ortega, E.M. & José Tarí, J. (2020) 'Multilevel research: Foundations and opportunities in management'. *BRQ Business Research Quarterly*. 23(4). SAGE Publications: pp.319–333.

Moliterno, T.P. & Mahony, D.M. (2011) 'Network Theory of Organization: A Multilevel Approach'. *Journal of Management*. 37(2). SAGE Publications Inc: pp.443–467.

Moss, D.M., Osborn, T.A. & Kaufman, D. (2003) Going Beyond the Boundaries. In: Kaufman, D., Moss, D.M., and Osborn, T.A. (eds) *Beyond the Boundaries: A Transdisciplinary Approach to Learning and Teaching*. Westport, CT.: Praeger Publishers, pp. 1–12.

Mowery, D.C., Oxley, J.E. & Silverman, B.S. (1996) 'Strategic alliances and interfirm knowledge transfer'. *Strategic Management Journal*. 17(S2): pp.77–91.

Müller, K., Rammer, C. & Trüby, J. (2009) 'The role of creative industries in industrial innovation'. *Innovation: Management, Policy & Practice*. 11(2): pp.148–168.

Narula, R. & Martínez-Noya, A. (2015) International R&D Alliances by Firms. In: Archibugi, D. and Filippetti, A. (eds) *The Handbook of Global Science, Technology, and Innovation*. Malden, MA.: John Wiley & Sons, Ltd, pp. 144–170.

Neelands, J., Belfiore, E., Firth, C., Hart, N., Perrin, L., Brock, S., Holdaway, D. & Woddis, J. (2015) *Enriching Britain: culture, creativity and growth*. Coventry: The University of Warwick.

Nelson, R.R. & Winter, S.G. (1982) *An Evolutionary Theory of Economic Change*. Cambridge, MA.: Harvard University Press.

Ness, I.J. & Riese, H. (2015) 'Openness, curiosity and respect: Underlying conditions for developing innovative knowledge and ideas between disciplines'. *Learning, Culture and Social Interaction*. 6: pp.29–39.

Nesta (2006) *Creating Growth: How can the UK develop world class creative businesses*. London: Nesta.

Newell, S., Tansley, C. & Huang, J. (2004) 'Social Capital and Knowledge Integration in an ERP Project Team: The Importance of Bridging AND Bonding'. *British Journal of Management*. 15(S1): pp.43–57.

Nissani, M. (1997) 'Ten cheers for interdisciplinarity: The case for interdisciplinary knowledge and research'. *The Social Science Journal*. 34(2): pp.201–216.

Nonaka, I. (1994) 'A Dynamic Theory of Organizational Knowledge Creation'. *Organization Science*. 5(1): pp.14–37.

Nonaka, I. & Toyama, R. (2003) 'The knowledge-creating theory revisited: knowledge creation as a synthesizing process'. *Knowledge Management Research & Practice*. 1(1): pp.2–10.

Nooteboom, B. (1992) 'Towards a dynamic theory of transactions'. *Journal of Evolutionary Economics*. 2(4): pp.281–299.

Nooteboom, B., Haverbeke, W.V., Duysters, G., Gilsing, V. & van den Oord, A. (2007) 'Optimal cognitive distance and absorptive capacity'. *Research Policy*. 36(7): pp.1016–1034.

Oakley, K. (2009) 'From Bohemia to Britart – art students over 50 years'. *Cultural Trends*. 18(4): pp.281–294.

O'Connor, J. (2000) 'The definition of the 'cultural industries''. *The European Journal of Arts Education*. 2(3): pp.15–27.

O'Connor, J. (2004) ''A Special Kind of City Knowledge': Innovative Clusters, Tacit Knowledge and the 'Creative City''. *Media International Australia*. 112(1): pp.131–149.

O'Connor, J. (2007) *The Cultural and Creative Industries: A Review of the Literature*. London: Creative Partnerships, Arts Council England.

O'Connor, J. (2009) 'Creative industries: a new direction?'. *International Journal of Cultural Policy*. 15(4): pp.387–402.

OECD (2014) *Tourism and the Creative Economy*. OECD Studies on Tourism. Paris: OECD Publishing.

Ofqual (2018) The Register of Regulated Qualifications. Available: https://register.ofqual.gov.uk/.

Ofqual (2019) Data tables for provisional entries for GCSE, AS and A level: summer 2019 exam series. Available: https://www.gov.uk/government/statistics/provisional-entries-for-gcse-as-and-a-level-summer-2019-exam-series.

Okhuysen, G.A. & Eisenhardt, K.M. (2002) 'Integrating Knowledge in Groups: How Formal Interventions Enable Flexibility'. *Organization Science*. 13(4): pp.370–386.

ONS (2019) The National Statistics Socio-economic classification (NS-SEC) - Office for National Statistics. Available: https://www.ons.gov.uk/methodology/classificationsandstandards/otherclassifications/thenationalstatisticssocioeconomicclassificationnssecrebasedonsoc2010.

Ordanini, A., Rubera, G. & Sala, M. (2008) 'Integrating Functional Knowledge and Embedding Learning in New Product Launches'. *Long Range Planning*. 41(1): pp.17–32.

Østergaard, C.R., Timmermans, B. & Kristinsson, K. (2011) 'Does a different view create something new? The effect of employee diversity on innovation'. *Research Policy*. 40(3): pp.500–509.

Patrignani, P., Conlon, G. & Hedges, S. (2017) *The earnings differentials associated with vocational education and training using the Longitudinal Education Outcomes data*. CVER Discussion Paper Series 007. London: The Centre for Vocational Education Research.

Paulin, D. & Suneson, K. (2012) 'Knowledge transfer, knowledge sharing and knowledge barriers–three blurry terms in KM'. *The Electronic Journal of Knowledge Management*. 10(1): pp.81–91.

Paulus, P.B. (2000) 'Groups, Teams, and Creativity: The Creative Potential of Idea-generating Groups'. *Applied Psychology: An International Review*. 49(2): pp.237–262.

Pavitt, K. (1998) 'Technologies, Products and Organization in the Innovating Firm: What Adam Smith Tells Us and Joseph Schumpeter Doesn't'. *Industrial and Corporate Change*. 7(3): pp.433–452.

Pelled, L.H., Eisenhardt, K.M. & Xin, K.R. (1999) 'Exploring the Black Box: An Analysis of Work Group Diversity, Conflict, and Performance'. *Administrative Science Quarterly*. 44(1): pp.1–28.

Peltoniemi, M. (2015) 'Cultural Industries: Product–Market Characteristics, Management Challenges and Industry Dynamics'. *International Journal of Management Reviews*. 17(1): pp.41–68.

Penrose, E. (1995) *The Theory of the Growth of the Firm*. Oxford: Oxford University Press.

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'Este, P., Fini, R., Geuna, A., Grimaldi, R., Hughes, A., et al. (2013) 'Academic engagement and commercialisation: A review of the literature on university–industry relations'. *Research Policy*. 42(2): pp.423–442.

Peterson, N.G., Mumford, M.D., Borman, W.C., Jeanneret, P.R., Fleishman, E.A., Levin, K.Y., Campion, M.A., Mayfield, M.S., Morgeson, F.P., Pearlman, K., et al. (2001) 'Understanding Work Using the Occupational Information Network (o*net): Implications for Practice and Research'. *Personnel Psychology*. 54(2): pp.451–492.

Peterson, R.A. (1992) 'Understanding audience segmentation: From elite and mass to omnivore and univore'. *Poetics*. 21(4): pp.243–258.

Pigden, L. & Moore, A.G. (2018) 'Employability outcomes for university joint honours graduates'. *Higher Education, Skills and Work-Based Learning*. 8(2): pp.195–210.

Pitt, R.N. & Tepper, S.A. (2012) *Double majors: Influences, identities, and impacts*. Nashville, TN.: The Curb Center, Vanderbilt University.

Ployhart, R.E. & Moliterno, T.P. (2011) 'Emergence of the Human Capital Resource: A Multilevel Model'. *Academy of Management Review*. 36(1). Academy of Management: pp.127–150.

Polanyi, M. (2009) *The Tacit Dimension*. Chicago, IL.: University of Chicago Press.

Postrel, S. (2002) 'Islands of Shared Knowledge: Specialization and Mutual Understanding in Problem-Solving Teams'. *Organization Science*. 13(3): pp.303–320.

Postrel, S. (2017) Effective Management of Collective Design Processes: Knowledge Profiles and the Sequential Ordering of Tasks. In: Tell, F., Berggren, C., Brusoni, S., and Van de Ven, A.H. (eds) *Managing Knowledge Integration Across Boundaries*. Oxford: Oxford University Press, pp. 39–56.

Potts, J. (2009) 'Introduction: Creative industries and innovation policy'. *Innovation: Management, Policy & Practice*. 11(2): pp.138–147.

Pratt, A.C. & Gornostaeva, G. (2009) The governance of innovation in the Film and Television industry: a case study of London, UK. In: Pratt, A.C. and Jeffcutt, P. (eds) *Creativity, Innovation and the Cultural Economy*. Oxon: Routledge, pp. 119–136.

Rauniar, R. (2005) *Knowledge integration in integrated product development: The role of team vision, mutual trust, and mutual influence on shared knowledge in product development performance*. Ph.D. The University of Toledo, Toledo, OH.

Ravasi, D. & Verona, G. (2001) 'Organising the process of knowledge integration: the benefits of structural ambiguity'. *Scandinavian Journal of Management*. 17(1): pp.41–66.

Reeder, M.C. & Tsacoumis, S. (2017) O*NET® Analyst Ratings of Occupational Skills: Analysis Cycle 17 Results, Human Resources Research Organization. Available: https://www.onetcenter.org/dl_files/AOSkills_17.pdf.

Rodríguez-Pose, A. & Lee, N. (2020) 'Hipsters vs. geeks? Creative workers, STEM and innovation in US cities'. *Cities*. 100: pp.1–9.

Root-Bernstein, R. (2015) 'Arts and crafts as adjuncts to STEM education to foster creativity in gifted and talented students'. *Asia Pacific Education Review*. 16(2): pp.203–212.

Rosch, T.A. & Reich, J.N. (1996) 'The enculturation of new faculty in higher education: A comparative investigation of three academic departments'. *Research in Higher Education*. 37(1): pp.115–131.

Ross, A. (2007) 'Nice work if you can get it: the mercurial career of creative industries policy'. *Work Organisation, Labour & Globalisation*. 1(1): pp.13–30.

Sainsbury, D. (2007) *The Race to the Top: A Review of Government's Science and Innovation Policies*. London: HM Treasury.

Sapsed, J., Nightingale, P., Camerani, R., Mateos-Garcia, J., Voss, G., Coad, A. & Byford, J. (2013) *The Brighton Fuse*. Brighton: Arts and Humanities Research Council.

Schmickl, C. & Kieser, A. (2008) 'How much do specialists have to learn from each other when they jointly develop radical product innovations?'. *Research Policy*. 37(3): pp.473–491.

Schmidt, E. (2011) MacTaggart Lecture. MediaGuardian Edinburgh International Television Festival, Edinburgh.

Schultz, T.W. (1961) 'Investment in Human Capital'. *American Economic Review*. 51(1): pp.1–17.

Schumpeter, J.A. (1934) *The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest and the Business Cycle*. Harvard Economic Studies; 46. Cambridge, MA.: Harvard University Press.

Scott, A.J. (2005) *On Hollywood: The Place, The Industry*. Princeton, NJ.: Princeton University Press.

Sedita, S.R., De Noni, I. & Pilotti, L. (2017) 'Out of the crisis: an empirical investigation of place-specific determinants of economic resilience'. *European Planning Studies*. 25(2): pp.155–180.

Sethi, R., Smith, D.C. & Park, C.W. (2001) 'Cross-Functional Product Development Teams, Creativity, and the Innovativeness of New Consumer Products'. *Journal of Marketing Research*. 38(1): pp.73–85.

Seymour, M. & Coyle, S. (2016) Towards a research agenda for adopting Agile Project Management in Creative Industries. In: *eProceedings of the 11th International Research Workshop on Information Technology Project Management (IRWITPM) Dublin, Ireland, December 10th, 2016*, 2016, pp. 166–175.

Siepel, J., Camerani, R., Masucci, M. & Pellegrino, G. (2016) *The fusion effect: the economic returns to combining arts and science skills*. London: Nesta.

Siepel, J., Camerani, R. & Masucci, M. (2019) 'Skills combinations and firm performance'. *Small Business Economics*. 0(0): pp.0–0.

Siepel, J., Velez Ospina, J., Camerani, R., Bloom, M., Masucci, M. & Casadei, P. (2021) *Creative Radar 2021: The Impact of COVID-19 on the UK's Creative Industries*. London: The Creative Industries Policy and Evidence Centre.

Simons, T., Pelled, L.H. & Smith, K.A. (1999) 'Making Use of Difference: Diversity, Debate, and Decision Comprehensiveness in Top Management Teams'. *The Academy of Management Journal*. 42(6): pp.662–673.

Skorton, D. & Bear, A. (eds) (2018) *The Integration of the Humanities and Arts with Sciences, Engineering, and Medicine in Higher Education: Branches from the Same Tree*. Washington, DC.: National Academies Press.

Sleeman, C. & Windsor, G. (2017) *A closer look at creatives: Using job adverts to identify the skill needs of creative talent*. London: Nesta.

Smith, C. (1998) *Creative Britain*. London: Faber & Faber.

Snow, C.P. (2012) *The Two Cultures*. Cambridge: Cambridge University Press.

Sochacka, N.W., Guyotte, K.W. & Walther, J. (2016) 'Learning Together: A Collaborative Autoethnographic Exploration of STEAM (STEM + the Arts) Education'. *Journal of Engineering Education*. 105(1): pp.15–42.

Söderlund, J. & Borg, E. (2018) 'Liminality in Management and Organization Studies: Process, Position and Place'. *International Journal of Management Reviews*. 20(4): pp.880–902.

Spelthann, V. & Haunschild, A. (2011) 'Organizational Creativity in Heterarchies: The Case of VFX Production'. *Creativity & Innovation Management*. 20(2): pp.100–107.

Spender, J.-C. (1996) 'Making knowledge the basis of a dynamic theory of the firm'. *Strategic Management Journal*. 17(S2): pp.45–62.

Spenner, K.I. (1990) 'Skill: Meanings, Methods, and Measures'. *Work and Occupations*. 17(4): pp.399–421.

Spilsbury, M. & Godward, C. (2013) *Classifying and measuring the Creative Industries*. London: Creative Skillset.

Squires, G. (1992) 'Interdisciplinarity in Higher Education in the United Kingdom'. *European Journal of Education*. 27(3): pp.201–210.

Stake, R.E. (1995) *The Art of Case Study Research*. Thousand Oaks, CA.: SAGE.

Star, S.L. & Griesemer, J.R. (1989) 'Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39'. *Social Studies of Science*. 19(3): pp.387–420.

Stark, D. (2011) *The Sense of Dissonance: Accounts of Worth in Economic Life*. Princeton, NJ.: Princeton University Press.

Starkey, K., Barnatt, C. & Tempest, S. (2000) 'Beyond Networks and Hierarchies: Latent Organizations in the U.K. Television Industry'. *Organization Science*. 11(3). INFORMS: pp.299–305.

Stock, G.N. & Tatikonda, M.V. (2008) 'The joint influence of technology uncertainty and interorganizational interaction on external technology integration success'. *Journal of Operations Management*. 26(1): pp.65–80.

Stoneman, P. (2010) *Soft Innovation: Economics, Product Aesthetics, and the Creative Industries*. Oxford: Oxford University Press.

Storper, M. & Christopherson, S. (1987) 'Flexible Specialization and Regional Industrial Agglomerations: The Case of the U.S. Motion Picture Industry'. *Annals of the Association of American Geographers*. 77(1): pp.104–117.

Szulanski, G. (1996) 'Exploring internal stickiness: Impediments to the transfer of best practice within the firm'. *Strategic Management Journal*. 17(S2): pp.27–43.

Szulanski, G. (2002) *Sticky Knowledge: Barriers to Knowing in the Firm*. London: SAGE.

Tanriverdi, H. & Venkatraman, N. (2005) 'Knowledge relatedness and the performance of multibusiness firms'. *Strategic Management Journal*. 26(2): pp.97–119.

Teece, D.J. (1982) 'Towards an economic theory of the multiproduct firm'. *Journal of Economic Behavior & Organization*. 3(1): pp.39–63.

Teece, D.J., Pisano, G. & Shuen, A. (1997) 'Dynamic Capabilities and Strategic Management'. *Strategic Management Journal*. 18(7): pp.509–534.

Tell, F. (2011) Knowledge integration and innovation: a survey of the field. In: Berggren, C., Bergek, A., Bengtsson, L., Hobday, M., and Söderlund, J. (eds) *Knowledge Integration and Innovation: Critical Challenges Facing International Technology-Based Firms*. Oxford: Oxford University Press, pp. 20–58.

Tell, F., Berggren, C., Brusoni, S. & van de Ven, A.H. (2017) Introduction: Managing Knowledge Across Boundaries. In: Tell, F., Berggren, C., Brusoni, S., and van de Ven, A.H. (eds) *Managing Knowledge Integration Across Boundaries*. Oxford: Oxford University Press.

Tempest, S. & Starkey, K. (2004) 'The Effects of Liminality on Individual and Organizational Learning'. *Organization Studies*. 25(4). SAGE Publications Ltd: pp.507–527.

Thatcher, M.E., Cha, H.S., Ahuja, M.K. & Pingry, D.E. (2011) IT Outsourcing: Assessing the Antecedents and Impacts of Knowledge Integration. In: *2011 44th Hawaii International Conference on System Sciences*, January 2011, pp. 1–10.

The Work Foundation (2007) *Staying ahead: the economic performance of the UK's creative industries*. London: The Work Foundation.

Throsby, D. (2001) *Economics and Culture*. Cambridge: Cambridge University Press.

Throsby, D. (2008a) 'Modelling the cultural industries'. *International Journal of Cultural Policy*. 14(3): pp.217–232.

Throsby, D. (2008b) 'The concentric circles model of the cultural industries'. *Cultural Trends*. 17(3): pp.147–164.

Tiwana, A. (2008) 'Do bridging ties complement strong ties? An empirical examination of alliance ambidexterity'. *Strategic Management Journal*. 29(3): pp.251–272.

Tiwana, A. & Mclean, E.R. (2005) 'Expertise integration and creativity in information systems development'. *Journal of Management Information Systems*. 22(1): pp.13–43.

Tödtling, F. & Grillitsch, M. (2015) 'Does Combinatorial Knowledge Lead to a Better Innovation Performance of Firms?'. *European Planning Studies*. 23(9): pp.1741–1758.

Turner, V. (1982) *From Ritual to Theatre: The Human Seriousness of Play*. New York City: PAJ Publications.

UCAS (2017) Calculate your UCAS Tariff points, University and Colleges Admissions Service. Available: https://www.ucas.com/ucas/tariff-calculator.

UCAS (2018) UCAS Tariff tables Tariff points for entry to higher education from 2019, University and Colleges Admissions Service. Available: https://www.ucas.com/file/63541/download?token=uz826-Cb.

UNCTAD (2010) *Creative Economy Report 2010*. United Nations Conference on Trade and Development.

UNESCO (2009) *The 2009 UNESCO framework for cultural statistics (FCS)*. United Nations Educational, Scientific and Cultural Organization Institute for Statistics.

UNESCO (2012) *Measuring the economic contribution of cultural industries: a review and assessment of current methodological approaches*. Montreal: United Nations Educational, Scientific and Cultural Organization Institute for Statistics.

UNESCO (2018) *Re/shaping cultural policies: advancing creativity for development: 2005 convention global report: 2018*. Paris: United Nations Educational, Scientific and Cultural Organization.

Uzzi, B. & Spiro, J. (2005) 'Collaboration and Creativity: The Small World Problem'. *American Journal of Sociology*. 111(2): pp.447–504.

Van de Ven, A. & Zahra, S.A. (2017) Boundary Spanning, Boundary Objects and Innovation. In: Tell, F., Berggren, C., Brusoni, S., and Van de Ven, A.H. (eds) *Managing Knowledge Integration Across Boundaries*. Oxford University Press, pp. 241–254.

van Gennep, A. (1960) *The Rites of Passage*. London: Routledge.

Van Nuys, A. (2020) *LinkedIn Learning 2020 Workplace Learning Report*. LinkedIn Learning.

Vidal Rodeiro, C.L. (2019) *Popularity of A Level subjects among university students*. Cambridge Assessment Research Report. Cambridge, UK: Cambridge Assessment.

Virani, T.E. & Pratt, A.C. (2015) *The creative SME: a cautionary tale*. Creativeworks London Working Paper Series 14. London: Creativeworks London.

von Hippel, E. (1994) ''Sticky Information' and the Locus of Problem Solving: Implications for Innovation'. *Management Science*. 40(4): pp.429–439.

Walker, I. & Zhu, Y. (2011) 'Differences by degree: Evidence of the net financial rates of return to undergraduate study for England and Wales'. *Economics of Education Review*. 30(6). Special Issue: Economic Returns to Education: pp.1177–1186.

Wallace, T. & Barber, A. (2013) *Fusion Skills: Perspectives and Good Practice*. London: Creative Skillset.

Ward, T.B., Smith, S.M. & Finke, R.A. (1999) Creative Cognition. In: Sternberg, R.J. (ed.) *Handbook of Creativity*. Cambridge: Cambridge University Press, pp. 189–221.

West, M.A. (2002) 'Sparkling Fountains or Stagnant Ponds: An Integrative Model of Creativity and Innovation Implementation in Work Groups'. *Applied Psychology*. 51(3): pp.355–387.

Wiersema, M.F. & Bantel, K.A. (1992) 'Top Management Team Demography and Corporate Strategic Change'. *The Academy of Management Journal*. 35(1): pp.91–121.

Willem, A., Scarbrough, H. & Buelens, M. (2008) 'Impact of coherent versus multiple identities on knowledge integration'. *Journal of Information Science*. 34(3): pp.370–386.

Williams, K.Y. & O'Reilly, C.A. (1998) 'Demography and diversity in organizations: A review of 40 years of research'. *Research in organizational behavior*. 20: pp.77–140.

Williamson, G. (2021) Guidance to the Office for Students — Allocation of the Higher Education Teaching Grant funding in the 2021 -22 Financial Year.

Windsor, G., Bakhshi, H. & Mateos-Garcia, J. (2016) *Skilled Migration and the UK's Creative Industries*. London: Nesta.

Winter, S.G. (2003) 'Understanding dynamic capabilities'. *Strategic Management Journal*. 24(10): pp.991–995.

WIPO (2003) *Guide on Surveying the Economic Contribution of the Copyright-Based Industries*. Geneva: World Intellectual Property Organization.

WIPO (2015) *Guide on Surveying the Economic Contribution of the Copyright-Based Industries: 2015 Revised edition*. Geneva: World Intellectual Property Organization.

Woiceshyn, J. & Daellenback, U. (2005) 'Integrative capability and technology adoption: evidence from oil firms'. *Industrial and Corporate Change*. 14(2): pp.307–342.

Wood, R.E. (1986) 'Task complexity: Definition of the construct'. *Organizational Behavior and Human Decision Processes*. 37(1): pp.60–82.

Wynn, T. & Harris, J. (2012) 'Toward A Stem + Arts Curriculum: Creating the Teacher Team'. *Art Education*. 65(5): pp.42–47.

Ybema, S., Beech, N. & Ellis, N. (2011) 'Transitional and perpetual liminality: An identity practice perspective'. *Anthropology Southern Africa*. 34(1–2). Routledge: pp.21–29.

Yin, R.K. (1981) 'The case study as a serious research strategy'. *Science communication*. 3(1): pp.97–114.

Yin, R.K. (2009) *Case Study Research: Design and Methods*. 4th ed. Applied social research methods v. 5. Los Angeles, CA.: Sage Publications.

Zahra, S.A. & George, G. (2002) 'Absorptive Capacity: A Review, Reconceptualization, and Extension'. *The Academy of Management Review*. 27(2): pp.185–203.

Zhang, X., Wang, X. & Zhao, W. (2020) 'Social capital and knowledge integration in interdisciplinary research teams: a multilevel analysis'. *Management Decision*. 59(8). Emerald Publishing Limited: pp.1972–1989.

Zollo, M. & Winter, S.G. (2002) 'Deliberate Learning and the Evolution of Dynamic Capabilities'. *Organization Science*. 13(3): pp.339–351.

7. Appendices

7.1. Appendix 1 – DCMS creative industries definition

Table 25 – Creative industries classification

SIC code	Description	Creative Industries Subsector
7021	Public relations and communication activities	Advertising and marketing
7311	Advertising agencies	
7312	Media representation	
7111	Architectural activities	Architecture
3212	Manufacture of jewellery and related articles	Crafts
7410	Specialised design activities	Design and designer fashion
5911	Motion picture, video and television programme activities	Film, TV, video, radio and photography
5912	Motion picture, video and television programme post-production activities	
5913	Motion picture, video and television programme distribution activities	
5914	Motion picture projection activities	
6010	Radio broadcasting	
6020	Television programming and broadcasting activities	
7420	Photographic activities	
5821	Publishing of computer games	IT, software and computer services
5829	Other software publishing	
6201	Computer programming activities	
6202	Computer consultancy activities	
9101	Library and archive activities	Museums, Galleries and Libraries
9102	Museum activities	
5920	Sound recording and Music publishing activities	Music, performing and visual arts
8552	Cultural education	
9001	Performing arts	
9002	Support activities to performing arts	
9003	Artistic creation	
9004	Operation of arts facilities	
5811	Book publishing	Publishing
5812	Publishing of directories and mailing lists	
5813	Publishing of newspapers	
5814	Publishing of journals and periodicals	
5819	Other publishing activities	
7430	Translation and interpretation activities	

Source: (DCMS, 2016)

7.2. Appendix 2 – Chapter 3 additional information

7.2.1. Data description table

Table 26 – Data description		
Data Type	**Description**	**Project**
Job role specifications	37 documents	Firm level
Project schedules	Full project schedule	Project A
	Full project schedule	Project B
	Full project schedule	Project C
Crew sheets	Full Crew Sheet	Project A
	Full Crew Sheet	Project B
	Full Crew Sheet	Project C
Minutes from post show review meetings	Main review meeting: 20 people in attendance Animation department review meeting: 10 people in attendance	Project A
	Main review meeting: 20 people in attendance	Project B
Staff surveys	137 responses	Project A
	139 responses	Project B
	202 responses	Project C
Interviews	• Senior executive, 67mins • Senior executive, 53mins • Head of department, 55mins • Head of department, 56mins • Head of department, 55mins	Firm level
	• VFX Producer, 59mins • CG Supervisor, 59mins • VFX Supervisor, 44mins • Comp Supervisor, 57mins • Jnr CFX Artist (trainee), 47mins	Project A
	• VFX Producer, 56mins • Animation Supervisor, 46mins • CG Supervisor, 51mins • Comp Supervisor, 47mins • Lead Rigging Technical Director, 45mins • Mid-level Modeller, 36mins	Project B
	• VFX Producer, 53mins • Animation Supervisor, 56mins • Comp Supervisor, 54mins • Junior FX Artist, 73mins	Project C
Meeting observations	6 meetings, 5hrs	Firm level

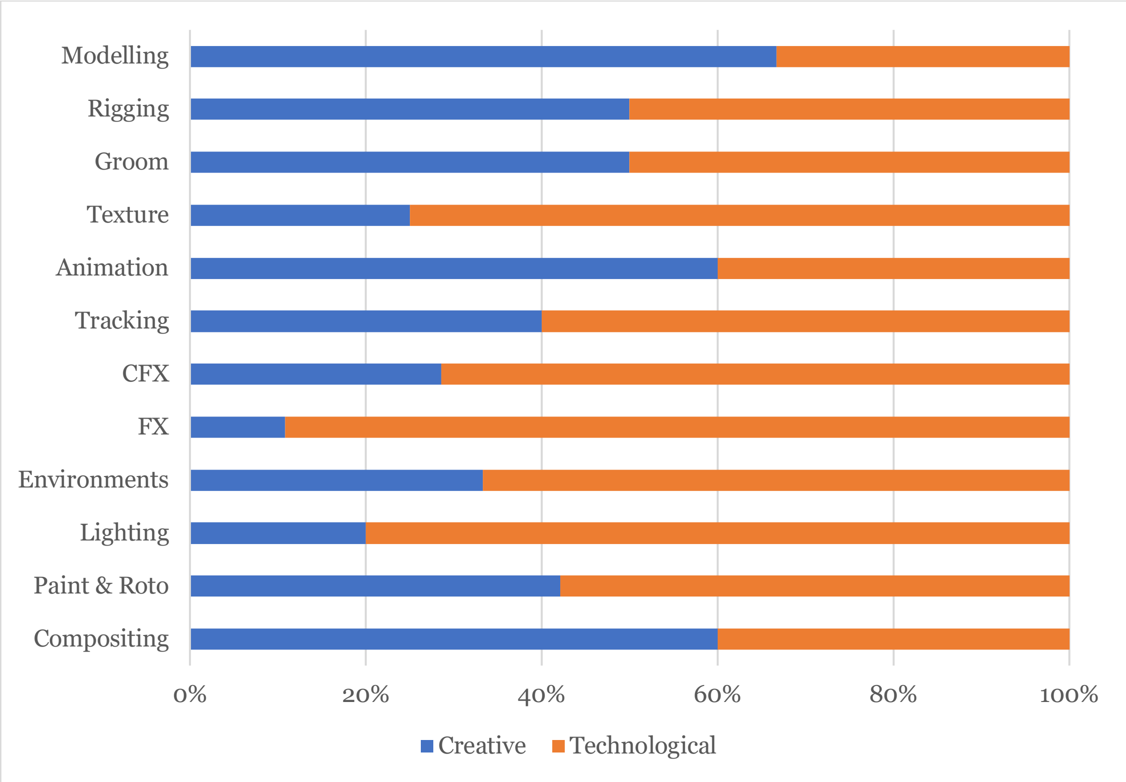
7.2.2. Job description coding

Table 27 – Job description coding	
- Knowledge of specific software packages (e.g. Maya, Nuke, Photoshop) - Coding skills (e.g. Python, C++) - Understanding of different operating systems (e.g. Unix, Linux) - Degree in computer science / computer engineering / computer graphics - Experience of software development - Mathematics background - Knowledge of digital formats	Technological
- Knowledge of human and animal anatomy - Life drawing skills - Understanding of physical motion, weight, balance, texture and form - Traditional art/animation background - Degree in art/animation/digital art/film - Knowledge of colour theory, lighting, perspective, scale and composition - Artistic ability and flair - Understanding of photography	Creative
- Communication skills - Interpersonal skills - Team player/team working - Ability to collaborate (both within team and across departments) - Ability to take direction - Ability to work towards a common goal - Understanding of full VFX process/process outside main department	Communication/collaboration
- Organisation skills - Project management skills - Time management skills - Budgets - Maintain morale - Scheduling - Leadership	Management
- Willingness/desire to learn - Can embrace change - Problem solving skills - Lateral thinking skills	Innovation

7.2.3. Breakdown of skills by department

Figure 12 below shows the proportion of codes ascribed to the categories 'Creative' and 'Technological' anywhere in the job description, for all job descriptions from each department. The departments are ordered by their position in the workflow.

Figure 12 – Creative/technological skills breakdown per department



7.2.4. Evaluation documents coding

Table 28 – Evaluation document coding	
Feedback Confusion Informal communication (e.g. phone calls, chats) Templates/wikis Communication between teams/departments Work in progress screenings Meetings Dallies	Communication
Morale Team work/feeling part of a team Help/support from others Trust Motivation Experience/new staff Respect Inspiration	Teamwork
Specific software issue	Technical issues
Skills issue Training issue Knowledge of software Knowledge of other departments work	Skills/training
Standardisation/formal procedures Time delay Work arriving late	Project management

7.2.5. Interview coding

Coding Hierarchy

1. **Common signs**
    1.1. Language
    1.2. Jargon
2. **Common codes**
    2.1. Pipeline
    2.2. Shotgun
    2.3. Documentation
3. **Common understanding**
    3.1. Feedback
    3.2. Iteration
        3.2.1. Uncertainty
    3.3. Creativity
4. **Common indexicality**
    4.1. Client briefs
    4.2. Dailies
    4.3. Boundary objects
        4.3.1. Drawings
        4.3.2. Acting
        4.3.3. References
5. **Common identity**
    5.1. Tribalism
    5.2. Heterarchy
    5.3. Respect
6. **Common culture**
    6.1. Ownership
    6.2. Social meetings
    6.3. Work in progress screenings
    6.4. Goals
7. **Innovation/learning**
    7.1. Problem solving
    7.2. Idea generation
8. **Diversity/specialisation**
    8.1. Playing to people's strengths
    8.2. Trust

Example quotes

1. Common signs	"The guys who do it, I find it hard to follow their conversation, they're very smart and they do all sorts of things that I have no idea about." "When it comes to technical things that I don't know much about, I'll just say, 'Guys, I don't know about this. How do I do that?' So, in a way, it's not translating, it's just leaning on each other's expertise and experience." "Maybe if I go right now to one other guy maybe sitting in animation and say, 'What do you do with VEX? What do you do usually in VOPs?' People were like, 'What are you talking about?'"
1.1. Language	"Even thought we might be speaking a slightly different language, which we do unify, so inner brow raiser is the common thing. What it means in terms of each other's particular area of interest and contribution is a bit different." "Clarity is difficult sometimes when you're conveying the nuances of, oh God no, how a camera pans across, following a character that's moving, you know, making sure you're using the right language. Common language, about cameras or whatever it is, so that we all understand each other"
1.2. Jargon	"The bake is like a technical term [...] 'The bake's still on the farm.' It's like, that makes absolutely no sense to people that don't know visual effects" "There is a lot of jargon, and you get different jargon in different departments. There are certainly things that I would need to ask for an explanation of if a CFX person or a rigger started talking to me with specifics"
2. Common codes	"We build tools and set-ups, and all kinds of things, to try to make sure that it's easy for people to do things the same way. Otherwise you're left with 90 things that look slightly different" "Because everything is so pipelined, and we've got databases that run everything, everything

	that's created is full of tags and information of what it is and what it's for"
2.1. Pipeline	"I know how to do it outside of the Framestore pipeline [...] but we have a very regimented and rigid process which is necessary to work efficiently, for communication to flow, for things to be very organised, and to work at a level of scale like we do" "They won't render anything unless it's in the Pipeline. If it's not done a certain way then you're not getting the render."
2.2. Shotgun	"I don't know if you know about Shotgun, that we use, it's like an organisation tool which is pretty amazing. All the shots are in there. It's like a vast database with all kinds of cool things you can do with it, organise people, let people know when there is stuff ready for them to work with." "People will just go on Shotgun and be like, 'Oh, I wonder what's happened to this?'"
2.3. Documentation	"We always have a Wiki page which has a breakdown of what certain tools do or how we have general tools and how they work and how we can achieve to do what we want." "Whenever I'm new to a show we always get like a brief, like welcome to the show. We always have a Wiki page and it tells us about each character and who they are and how they work. We will look at early examples that were shown to our clients, that they liked. That is the standard that needs to be kept"
3. Common understanding	"Essentially, everything when it's about creative work it's a bit subjective. So, it's all about understanding what people mean, understanding how to build a picture that the end result can be subjective, like, I can like it and someone else might not." "We have so many different departments who work in so many different skillsets and backgrounds, it's exciting in one way because you've got so much talent under one roof but in another every department has their own set of rules. Every department has their own set of workings, so someone could say use such and such

	a tool in the rigging department and I'd go, 'What?'"
3.1. Feedback	"Sometimes you want to get feedback on the formation or something like that, which is, you know, everyone can see those issues like, 'Oh, the arm is exploding,' or something. But there's also the more the bigger picture, like, I want to know if the character in general is doing what he should be doing" "I think, understanding a little bit more why the director had to do what he had to do helps them go through that process, and understand that they have to do these versions, not because someone just changed their mind on the day, but because there were reasons behind it."
3.2. Iteration	"What we usually do is lots and lots of iterations on something, and just work from notes that we get form the supervisor or from the client, and then just do another submission. Then sometimes they might say , 'Go back to the old submission with this element' or, "Keep this element'" "In a perfect world it would be linear, but it's not, because they'll start animating and realise, 'Oh, there's a part of the model that has to change' [...] And it will go back to modelling. Which means rigging might have to fix something. Then they'll release a new rig. Then the animators will get in. The animators will say, 'Oh, you know what? I actually need the character to move this way' Then they go back. Do you know what I mean? So it is iterative and it is bouncing back and forth." "You actually create something like a collective. Sometimes you get too used to some stuff that you don't understand anymore what is happening because you are iterating this bonfire over and over and over and over. At the end it looks the same to your eyes and you don't know anymore where you were, where you need to be [...] Then another point of view is always helping, definitely."
3.2.1. Uncertainty	"In the beginning it's probably less clear, because you can talk as much, but until the shots start to come up, it's quite hard to gauge."

	“The first thing is that sometimes they give you a very rough idea, say, ‘I want interaction with it’ and that's it. That is the start. You have to think about how it could be interacting and you try maybe to find references. You try to find what is happening, if, I don't know, an eagle is swinging across, I don't know, some clouds or whatever. You try to find something that is real to have an imagination of what that is and trying to be, let's say, on the same page of your supervisor. It's more thinking about it.”
3.3. Creativity	“Then there’s shots where you want to make the audience cry because of the way the eyes on the character are looking up and... That’s not a mechanical process. That’s not a technical process alone. It is that too. But you're looking for that artistic spark, that creative spark, that person who can express things emotionally and understands the story and all those kinds of things.”
4. Common indexicality	“You know, everybody's completely different. I think it's just as long as there's an understanding of why you're doing something and what the supervisor's trying to get at.” "I think having an understanding of what people do is quite important. I don’t have to be able to do the work myself. If I understand roughly what, or how long things might take, how complex something might be and whether the technology even allows us to do something or not, whether we need to develop new technology and where there is R&D time involved, that helps a lot.” “I think it’s very important for people to understand how their work fits within the overall scope, but also other departments, in order to deliver the work they need to deliver.”
4.1. Client briefs	“It makes a big difference, I think, because your client has got more trust in you if they know you know what you’re doing and they’ve worked with you before, because there’s not that early stage of sussing each other out”
4.2. Dailies	“Because the person who's leading the dailies, hopefully, is just the conduit of what the final result is trying to be. Obviously, they put their own

	stamp on it as well, but as long as everyone knows what the final result is meant to be, then it's just filling in that part." "There are many times in dailies where we're seeing the supervisor who will- the supervisor knows the show backwards. He'll sit with his laser pen and maybe point out this isn't correct, or this is not right. They always have the right vision in their heads, so they're always keeping that direction correct. They will make sure that we're following the correct brief" "That's why it's important to be there. We always have a production coordinator who will take notes, but I always believe in being there. You can speak to the supervisor yourself and get the exact information you need. At the end of the day it's just trying to understand what they need to get the shot done."
4.3. Boundary objects	"Because if you're in a room you can talk about it and you can actually open it up as a discussion. So the VFX supervisor might say, 'I think the groom on this needs changing.' Then he can point and see what he's got problems with. Or the comp doesn't work because the depth of field is wrong, and he can go and say, 'I'm looking at this thing over here, and this is out of focus and this doesn't quite match it.' So you suddenly get a clearer understanding. Rather than getting a note in dailies which says, 'Change the focus', and it's just like, 'What do they want me to change it to?'"
4.3.1. Drawings	"Where language stops working, sometimes I just stop talking and sometimes you can just draw. So, in RV, the software we use to review, you can sit and sometimes, just doing a drawing over three or four frames and you're like, 'Right, overlap like so.' 'Ah, now I get it.'" "They did this thing called sketch vis, which was a new thing that they came up with together [...] they are literally just, it's almost like storyboarding on top of the frames"
4.3.2. Acting	"They'll also do lots of things on the floor, they'll be actually acting out stuff and then filming each other doing it for their reference stuff"

	"I act a lot. So, I tell animators to bring their phones and install the camera that can record at 24 frames per second. Then I stand up and I hit play on the audio and I just act it out in front of them and I say, 'Something like this. You see.'"
4.3.3. References	"Say if we had a character is in a windy set up and they're wearing a leather coat and they need to have a bit of wind, they'll say, 'That looks too tight.' You look at the reference and it's like but, this is what the reference does. You can sometimes go back and say, 'Sorry, but take a look at this. This is a representation of what we have to work with, we're trying to make this look the same.'" "We tend to start off with a lot of mood boards as well. We collect reference, general reference, that might be relatable or might be inspiring for a design. It might not directly relate to it, but might inspire something that goes into the design. We'll do mood boards. The good thing about mood boards, as well, is at the start it helps the director come to the conclusion of what they do and what they don't like. So it saves us time going down a design route that they end up not liking."
5. Common identity	"You have really quite different people all working in the same team with very different backgrounds and approaches" "I might see something and I think that looks good, whereas another supervisor might not. Then the artist doing it may not see it the same way, so you might get, like, three people with completely different views, but it tends to get worked out." "Production like to work in a certain way, we like to have standardised tasks and schedules and everything, but everyone is very different and they bring their different qualities to the table and they all... It helps make the shows a bit more interesting. [...] It's a real mixed bag, I think, of different personalities and different ways of working." "Especially in the early stages, you just need lots of different people with lots of different ideas on this."
5.1. Tribalism	"Every department has a different personality. They're all very different and so it's funny. You

	wouldn't think that it would be quite that generalised, but there are definitely tribes." "I don't think there's a negative element to the tribalism, but I do think it exists in a very natural way. Because there are teams, and they have lunch together a lot, and they join together."
5.2. Heterarchy	"There definitely is the conflict of different opinions. The artist wants to make something that looks incredible and does all of these things. Then the technical person says, 'It's not really possible to do that.' We have to compromise and rein it in a bit." "It's non-hierarchical in the sense that [...] anyone can have a good idea anywhere, and anyone has the ability to make change anywhere if it's a good idea."
5.3. Respect	"I think if you're one of the specialists, you probably have some understanding of what other people do, particularly people you work with most closely. But then you're also aware that they are specialists in their own field, and I think people are very respectful of each other." "That has helped to build trust, build engagement and build a mutual respect for the value of each other's time, but also the fact that, right from the get-go, the person sitting opposite you knows what they're talking about." "I think there's a lot of emphasis placed on your ability, certainly at the more senior levels, to communicate and to properly listen, express, respect, trust, and all those sorts of words. That just makes it a lot easier, then, to do things."
6. Common culture	"Even when it was really, really tough, we were kind of like, 'Well, it's really hard but damn you, [key character], you're so lovely and cute and you look at us in that way and it's all worthwhile.'" "Because we think in very different ways, but it's really for a common goal." "Everyone knows what the end goal is. People don't take it personally. Again, it's a team effort." "People who worked on that movie still feel a cultural pride in that movie. Sometimes that culture is bound up in the nature of the work

	that's being produce as well as the division or the company itself." "As a team it's very important to allow everyone to express their creativity, but still make sure they all work towards the same goal [...] you kind of want to make sure they go in the same direction, but still having freedom to express their creative views. "
6.1. Ownership	"I think for most people it's very important, owning their work. I think when you stop doing that people get quite despondent about the stuff that they're doing." "I'm proud of the work I do. And I'm always happy to see it [...] it's always like a bunch of Framestore people clapping by when you have a crew screening. I feel like it's more like a collaborative clap [...] The efforts of you combined [...] More than every individual person." "So it helps the company, in general, to have that ownership. Wanting to make sure and maintain, so that the design does follow through all the way through to the finish line."
6.2. Social meetings	"We have a toast club which is like a 15-minute little toast- we all go and have a cup of tea and toast, take a break, talk about stuff. It's a nice little chance to [...] just go, because it's important to get up from your desk for 15-minutes and go and have a little breather" "Their [CFX department] nickname here is cake effects, because they have cake every Friday. They're known for it." "The lighting team all go on holiday together on a canal boat, on multiple canal boats because there are quite a few of them, every summer. The environments team do cocktails on a Friday, everyone takes it in turns to come up with a cocktail."
6.3. Work in progress screenings	"Usually, up to two times a day, we'll sit down on a sofa and show everything on a big screen. We'll, internally, review our own work. Everyone can have an opinion. Everyone is there to help each other out. We're all human, you can get stuck sometimes. That's why, as a group of people, we

	all bounce ideas of each other, just to get a project through" "We try to do as regular as possible WIP screenings for the teams to say, 'Look at all this work you're doing, doesn't it look great?'" "It's inspiring as well, because there are certain films that… The last couple of times, going down the WIP screening… You see what other people are working on, whether it's a commercial or a TV project or a film. Sometimes it's like, 'Wow, that's great.' It makes you realise, re-realise, that it is a really creative company to work in."
6.4. Goals	"The different areas in visual effects, they all do lots of different versions of what they're doing as we do lots of versions of our concepts. Everyone is used to that way of working. Everyone knows what the end goal is. People don't take it personally. Again, it's a team effort." "You're thinking about a bigger picture thing. It's not just about the individual shot that somebody is working on, although that will have its own individual issues, but it's trying to come up with something that can solve problems for lots of people. That is generally what you're doing most of the time."
7. Innovation/learning	"It can always be better. I don't know a single picture that someone has said, 'This is perfect.'. Everyone is like, 'If I had two more days I could do this, this and this.'" "That is the way I like to work with my team, so that everybody's presenting their ideas. They are being creative. They are bringing ideas." "I think you want to have that diversity, I think that's key, because that will give you all different areas of ideas. […] I think the more diverse… The more freshness someone can give to the room, the better. It just keeps the ideas more original."
7.1. Problem solving	"I think really that's part and parcel of everything we do is solve problems. Because anything that can be automated is automated. If it's a procedure that can be made efficient and automated we've automated it. So a lot of the work we tend to do involves problem solving, involves

	coming up with a creative and efficient way to deliver some kind of effect.” “Sometimes on a job your solutions are socially arrived at between those teams rather than being prescriptive.” “There are some problems where you just need another way of thinking. Sometimes you just hit this brick wall of, like, “We can’t solve this problem,” and it just needs somebody to be like, “Why don’t we do this?””
7.2. Idea generation	“When you see it’s not working, it’s quite rare that everybody’s just like, ‘I don’t know what to do.’ Normally, somebody’s like, ‘Why don’t we try this?’ You normally end up trying a few different things.” “We’re kind of similar, but we all approach things in a different way. I think that’s quite good because, rather than being one person trying to figure out how to do something, it’s, kind of, ‘What do you think?’ We all sit down and come up with it – come up with suggestions.” “I'm quite open in the aspect of if somebody does something that I didn’t expect, I don’t think, ‘This is not what I expected, screw it. I want you to do this!’ I'm like, ‘Oh yes, okay, I didn’t but it works. It’s cool. Let’s send this.’ I'm not like, ‘What the fuck you did?’ I'm open to that, that is part of it.” “Just give me something. Doesn't matter. Just wing it. Doesn't matter if it's crap. Literally, just throw something out there, because having the conversation, all of a sudden you can progress the idea”
8. Diversity/specialisation	“We have a lot of technical people who don’t understand how to make things look pretty, and people who make things pretty but don’t know how to make things work, so it’s quite a balancing act to have them work together.” “Some people, maybe they don't have too much experience or they are so specialised that they actually don't know what is happening on other components.”

	"You really want them to focus quite exclusively on their own area of specialism because if they're worrying about understanding the bit upstream or downstream from them, they're probably not progressing in their own speciality enough. They're probably diversifying too much."
8.1. Playing to people's strengths	"I think whenever we have a project, you try and put the right people in the right roles, because you know that you'll get the best out of them if you put them in this particular role." "The whole idea is that you have people who do a specific job and do it really well. Then you have other people who organise the communication and everything to work together" "So, you give the artistic people the look development side of things that don't require too much technical skill, and then if they do, you pair them up with a technical comper who can feed them the technical things. So, it's almost like buddying people up to get the result"
8.2. Trust	"I think there's, kind of, almost an element of trust that comes from that as well, because no one really interferes in each other's jobs because there's just like, 'I know that they've got that. It's fine.'" "It's a sense of conversation. You can develop a first level of trust just by talking to somebody." "I think a big part of it too, and I've heard this from very diverse different groups, is that Framestore gives people trust. And I think that's so important. It's very careful to hire really good people and then trust them to do their job. And I think that's where you get amazing results." "Again, to me, I would just come back to that point about trusting people and having some faith in people and giving them some leeway to do stuff"

7.2.6. Indicative interview guide

General

1. What did your role on project X entail?
2. What was the most challenging aspects of the project?
3. What were the most enjoyable aspects of the project?
4. What part of the project are you most proud of?
5. How typical was project X in terms of the work you do here?

Integration

1. One of the things that seemed to come up a lot in the post-show review was communication, how would you assess the level of communication on the show?
   a. Why do you think that was?
   b. Are there structures in place to help with communication?
2. So my research is looking at how people with different skills work together, do you think people from different departments have different skills or different ways of doing things?
   a. Do you think that difference is generally a positive thing or a negative thing?
3. How would you describe each department?
4. How well do you think people from different departments get on?
   a. What do you think helps/hinders this?

Syntactic, semantic, pragmatic

1. There seems to me to be a lot of jargon used here, do you ever find that an issue?
2. How much do you think people from different departments understand each other?
3. Do you think Framestore has a particular culture?
   a. How would you describe that culture?

Innovation

1. How innovative do you think Framestore is?
   a. Why is that?
   b. What do you think makes Framestore innovative?
   c. Where does that innovation come from?

7.3. Appendix 3 – Chapter 4 additional information

7.3.1. Knowledge bases definition

Table 29 – Knowledge bases categorisation

SIC code	Description	Knowledge base
20	Manufacture of chemicals and chemical products	Analytic
21	Manufacture of basic pharmaceutical products and pharmaceutical preparations	
26	Manufacture of computer, electronic and optical products	
72	Scientific research and development	
58	Publishing, audiovisual and broadcasting activities	Symbolic
59	Publishing, audiovisual and broadcasting activities	
60	Publishing, audiovisual and broadcasting activities	
62	IT and other information services	
63	IT and other information services	
90	Arts, entertainment and recreation	
91	Arts, entertainment and recreation	
92	Arts, entertainment and recreation	
93	Arts, entertainment and recreation	
10	Manufacture of food products, beverages and tobacco products	Synthetic
11	Manufacture of food products, beverages and tobacco products	
12	Manufacture of food products, beverages and tobacco products	
13	Manufacture of textiles, wearing apparel, leather and related products	
14	Manufacture of textiles, wearing apparel, leather and related products	
15	Manufacture of textiles, wearing apparel, leather and related products	
16	Manufacture of wood and paper products; printing and reproduction of recorded media	
17	Manufacture of wood and paper products; printing and reproduction of recorded media	
18	Manufacture of wood and paper products; printing and reproduction of recorded media	
19	Manufacture of coke and refined petroleum products	
22	Manufacture of rubber and plastics products, and other non-metallic mineral products	
23	Manufacture of rubber and plastics products, and other non-metallic mineral products	
24	Manufacture of basic metals and fabricated metal products, except machinery and equipment	
25	Manufacture of basic metals and fabricated metal products, except machinery and equipment	
27	Manufacture of electrical equipment	
28	Manufacture of machinery and equipment n.e.c.	
29	Manufacture of transport equipment	
30	Manufacture of transport equipment	
31	Other manufacturing; repair and installation of machinery and equipment	
32	Other manufacturing; repair and installation of machinery and equipment	
33	Other manufacturing; repair and installation of machinery and equipment	
64	Financial and insurance activities	
65	Financial and insurance activities	
66	Financial and insurance activities	
68	Real estate activities	
77	Rental and leasing activities	

Source: (Sedita et al., 2017)

7.3.2. Additional tables

Table 30 – All organisations funded by InnovateUK 2004-2020

	Unique organisations N (% subset) [% total]	Unique projects N (% subset) [% total]	Occasions awarded N (% subset) [% total]	Occasions lead organisation N (% subset) [% total]	Total Project Funding (£Mil)
Creative industries	726 (100%) [10.3%]	827 (100%) [15.8%]	1040 (100%) [5.9%]	420 (100%) [8.0%]	£188.8M
Advertising and marketing	12 (1.7%) [0.2%]	15 (1.8%) [0.3%]	16 (1.5%) [0.1%]	5 (1.2%) [0.1%]	£2.3M
Architecture	45 (6.2%) [0.6%]	67 (8.1%) [1.3%]	71 (6.8%) [0.4%]	40 (9.5%) [0.8%]	£4.3M
Crafts	1 (0.1%) [0.0%]	1 (0.1%) [0.0%]	1 (0.1%) [0.0%]	1 (0.2%) [0.0%]	£0.0M
Design: product, graphic and fashion design	59 (8.1%) [0.8%]	75 (9.1%) [1.4%]	76 (7.3%) [0.4%]	26 (6.2%) [0.5%]	£21.9M
Film, TV, video, radio and photography	54 (7.4%) [0.8%]	71 (8.6%) [1.4%]	84 (8.1%) [0.5%]	33 (7.9%) [0.6%]	£16.0M
IT, software and computer services	511 (70.4%) [7.3%]	637 (77.0%) [12.2%]	739 (71.1%) [4.2%]	298 (71.0%) [5.7%]	£137.8M
Museums, galleries and libraries	2 (0.3%) [0.0%]	2 (0.2%) [0.0%]	2 (0.2%) [0.0%]	0 (0.0%) [0.0%]	£0.0M
Music, performing and visual arts	30 (4.1%) [0.4%]	27 (3.3%) [0.5%]	32 (3.1%) [0.2%]	7 (1.7%) [0.1%]	£4.2M
Publishing	12 (1.7%) [0.2%]	19 (2.3%) [0.4%]	19 (1.8%) [0.1%]	10 (2.4%) [0.2%]	£2.3M
Other industries	5524 (100%) [78.4%]	4827 (100%) [92.1%]	12057 (100%) [68.2%]	4465 (100%) [85.3%]	£2503.5M
A (Agriculture, Forestry and Fishing)	112 (2.0%) [1.6%]	161 (3.3%) [3.1%]	233 (1.9%) [1.3%]	69 (1.5%) [1.3%]	£29.1M
B (Mining and Quarrying)	42 (0.8%) [0.6%]	63 (1.3%) [1.2%]	82 (0.7%) [0.5%]	18 (0.4%) [0.3%]	£8.1M
C (Manufacturing)	1881 (34.1%) [26.7%]	2533 (52.5%) [48.3%]	4265 (35.4%) [24.1%]	1547 (34.6%) [29.5%]	£918.5M

D (Electricity, Gas, Steam and Air Conditioning Supply)	65 (1.2%) [0.9%]	125 (2.6%) [2.4%]	149 (1.2%) [0.8%]	41 (0.9%) [0.8%]	£33.6M
E (Water Supply; Sewerage, Waste Management and Remediation Activities)	64 (1.2%) [0.9%]	84 (1.7%) [1.6%]	103 (0.9%) [0.6%]	27 (0.6%) [0.5%]	£7.0M
F (Construction)	145 (2.6%) [2.1%]	229 (4.7%) [4.4%]	263 (2.2%) [1.5%]	80 (1.8%) [1.5%]	£27.8M
G (Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles)	269 (4.9%) [3.8%]	387 (8.0%) [7.4%]	460 (3.8%) [2.6%]	132 (3.0%) [2.5%]	£52.5M
H (Transportation and Storage)	90 (1.6%) [1.3%]	124 (2.6%) [2.4%]	154 (1.3%) [0.9%]	30 (0.7%) [0.6%]	£27.9M
I (Accommodation and Food Service Activities)	8 (0.1%) [0.1%]	8 (0.2%) [0.2%]	8 (0.1%) [0.0%]	4 (0.1%) [0.1%]	£0.5M
J (Information and Communication)	379 (6.9%) [5.4%]	548 (11.4%) [10.5%]	650 (5.4%) [3.7%]	271 (6.1%) [5.2%]	£119.3M
K (Financial and Insurance Activities)	61 (1.1%) [0.9%]	84 (1.7%) [1.6%]	88 (0.7%) [0.5%]	17 (0.4%) [0.3%]	£15.9M
L (Real Estate Activities)	39 (0.7%) [0.6%]	53 (1.1%) [1.6%]	53 (0.4%) [0.3%]	16 (0.4%) [0.3%]	£9.0M
M (Professional, Scientific and Technical Activities)	1718 (31.1%) [24.4%]	2912 (60.3%) [55.6%]	4177 (34.6%) [23.6%]	1835 (41.1%) [35.0%]	£1053.6M
N (Administrative and Support Service Activities)	355 (6.4%) [5.0%]	522 (10.8%) [10.0%]	567 (4.7%) [3.2%]	197 (4.4%) [3.8%]	£93.1M
O (Public Administration and Defence; Compulsory Social Security)	13 (0.2%) [0.2%]	96 (2.0%) [1.8%]	102 (0.8%) [0.6%]	30 (0.7%) [0.6%]	£18.4M
P (Education)	24 (0.4%) [0.3%]	125 (2.6%) [2.4%]	126 (1.0%) [0.7%]	19 (0.4%) [0.4%]	£34.2M
Q (Human Health and Social Work Activities)	99 (1.8%) [1.4%]	115 (2.4%) [2.2%]	139 (1.2%) [0.8%]	55 (1.2%) [1.1%]	£23.3M
R (Arts, Entertainment and Recreation)	11 (0.2%) [0.2%]	10 (0.2%) [0.2%]	12 (0.1%) [0.1%]	0 (0.0%) [0.0%]	£1.7M
S (Other Service Activities)	147 (2.7%) [2.1%]	397 (8.2%) [7.6%]	423 (3.5%) [2.4%]	77 (1.7%) [1.5%]	£30.0M
T (Activities of Households as Employers; Undifferentiated Goods-and Services-Producing Activities of Households for Own Use)	1 (0.0%) [0.0%]	1 (0.0%) [0.0%]	1 (0.0%) [0.0%]	0 (0.0%) [0.0%]	£0.0M
U (Activities of Extraterritorial Organisations and Bodies)	1 (0.0%) [0.0%]	2 (0.0%) [0.0%]	2 (0.0%) [0.0%]	0 (0.0%) [0.0%]	£0.0M

Other organisation type	438 (100%) [6.2%]	2916 (100%) [55.6%]	4025 (100%) [22.8%]	223 (100%) [4.3%]	£921.2M
Academic	130 (29.7%) [1.8%]	2703 (92.7%) [51.6%]	3435 (85.3%) [19.4%]	131 (58.7%) [2.5%]	£691.0M
Charity	47 (10.7%) [0.7%]	56 (1.9%) [1.1%]	61 (1.5%) [0.3%]	24 (10.8%) [0.5%]	£4.8M
NHS	92 (21.0%) [1.3%]	117 (4.0%) [2.2%]	171 (4.2%) [1.0%]	13 (5.8%) [0.2%]	£41.1M
Public Service Organisation	141 (32.2%) [2.0%]	195 (6.7%) [3.7%]	258 (6.4%) [1.5%]	42 (18.8%) [0.8%]	£169.6M
Public Sector Research Establishment	28 (6.4%) [0.4%]	98 (3.7%) [1.9%]	100 (2.5%) [0.6%]	13 (5.8%) [0.2%]	£14.6M
Non-UK	69 (100%) [1.0%]	62 (100%) [1.2%]	75 (100%) [0.4%]	2 (100%) [0.0%]	£3.4M
Unknown	288 (100%) [4.1%]	452 (100%) [8.6%]	490 (100%) [2.8%]	126 (100%) [2.4%]	£69.7M
Total	7045 (–) [100%]	5241 (–) [100%]	17687 (–) [100%]	5236 (–) [100%]	£3686.6M

Table 31 – Funding awards for all organisations

	Unique awards per organisation (N)	Proportion of awards as lead (%)	Mean funding per organisation (£)	Median funding per organisation (£)	Mean funding per occasion funded (£)	Median funding per occasion funded (£)
Creative industries	1.43	40%	£260,551	£129,594	£195,255	£114,000
Advertising and marketing	1.33	31%	£192,020	£45,162	£144,015	£46,649
Architecture	1.58	56%	£95,945	£56,085	£64,441	£56,085
Crafts	1.00	100%	£0	£0	£0	£0
Design: product, graphic and fashion design	1.29	34%	£371,502	£75,572	£332,101	£94,336
Film, TV, video, radio and photography	1.56	39%	£295,526	£132,016	£204,595	£137,489
IT, software and computer services	1.45	40%	£270,425	£142,234	£199,766	£124,968
Museums, galleries and libraries	1.00	0%	£0	£0	£0	£0
Music, performing and visual arts	1.07	22%	£139,882	£61,982	£131,139	£72,498
Publishing	1.58	53%	£189,805	£127,142	£126,537	£114,950
Other industries	2.18	37%	£453,138	£105,504	£223,426	£93,656
A (Agriculture, Forestry and Fishing)	2.08	30%	£259,770	£53,494	£131,648	£34,842
B (Mining and Quarrying)	1.95	22%	£193,602	£84,265	£105,601	£49,944
C (Manufacturing)	2.27	36%	£488,328	£100,218	£229,121	£87,286
D (Electricity, Gas, Steam and Air Conditioning Supply)	2.29	28%	£516,828	£165,084	£247,013	£37,247
E (Water Supply; Sewerage, Waste Management and Remediation Activities)	1.61	26%	£109,952	£32,315	£71,080	£19,779
F (Construction)	1.81	30%	£192,016	£68,000	£108,759	£57,604
G (Wholesale and Retail Trade; Repair of Motor Vehicles and Motorcycles)	1.71	29%	£195,252	£67,354	£121,020	£45,721
H (Transportation and Storage)	1.71	19%	£309,450	£70,345	£197,522	£63,287

I (Accommodation and Food Service Activities)	1.00	50%	£58,286	£21,681	£66,612	£27,362
J (Information and Communication)	1.72	42%	£313,791	£127,094	£197,476	£123,888
K (Financial and Insurance Activities)	1.44	19%	£260,978	£73,725	£201,515	£54,500
L (Real Estate Activities)	1.36	30%	£229,625	£34,000	£175,595	£48,000
M (Professional, Scientific and Technical Activities)	2.43	44%	£613,288	£163,150	£273,670	£122,036
N (Administrative and Support Service Activities)	1.60	35%	£262,124	£95,822	£176,239	£81,063
O (Public Administration and Defence; Compulsory Social Security)	7.85	29%	£1,412,622	£917,300	£183,641	£112,482
P (Education)	5.25	15%	£1,423,951	£45,415	£297,172	£123,676
Q (Human Health and Social Work Activities)	1.40	40%	£235,578	£78,770	£185,097	£105,986
R (Arts, Entertainment and Recreation)	1.09	0%	£153,688	£53,470	£140,880	£50,855
S (Other Service Activities)	2.88	18%	£204,185	£37,847	£83,841	£32,691
T (Activities of Households as Employers; Undifferentiated Goods-and Services-Producing Activities of Households for Own Use)	1.00	0%	£0	£0	£0	£0
U (Activities of Extraterritorial Organisations and Bodies)	2.00	0%	£0	£0	£0	£0
Other organisation types	9.19	6%	£2,103,241	£185,100	£244,226	£131,886
Academic	26.42	4%	£5,315,759	£1,447,698	£214,345	£140,159
Charity	1.30	39%	£103,120	£49,958	£82,147	£42,674
NHS	1.86	8%	£447,373	£204,797	£253,912	£116,579
Public Service Organisation	1.83	16%	£1,202,662	£104,902	£712,605	£87,271
Public Sector Research Establishment	3.57	13%	£521,095	£176,002	£163,940	£112,100
Non-UK	1.09	3%	£49,963	£0	£52,234	£0

Unknown	1.70	26%	£241,880	£34,304	£151,768	£41,408
Total Population (for reference)	*2.51*	*30%*	*£523,296*	*£104,227*	*£223,852*	*£100,000*