Particle Physics in Public:

Legitimising Curiosity-driven Research on the

Higgs Boson and beyond

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Declaration

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

Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

Signature: Chihwei Yeh

Date: 22 May 2019

Acknowledgement

Writing a thesis is like long-distance running: while aiming for the destination, numerous thoughts come and go through the mind; sensations are overwhelmed by the lungs breathing and heart beating, and every step forward is a war with oneself. However, when the time comes to look back, I can appreciate how beautiful the scenery along the journey was, including the people, places and events to which I must express my gratitude.

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Writing a thesis is like long-distance running. I will always remember the beautiful scenery along the journey and keep moving.

Abstract

The publicity surrounding the discovery of the Higgs boson hints at the enduring status of curiosity-driven research in modern society. However, the contemporary governance of scientific research emphasises efficiency, impact and social responsibility. In this context, the value and importance of the Higgs boson demands justification. This thesis therefore examines the ways in which members of the particle and high-energy physics community account for themselves and their scientific contributions at the nexus of science, policy and society. The qualitative evaluation of the outcome and performance of scientific research inevitably references researchers' accounts of their actions. Hence, the aim of this thesis is to develop an analytic framework that can unravel the construction of the value of research and examine the characteristics of the justifications offered.

The methodology of this thesis is inspired by the Analysis of Scientific Discourse (ASD) proposed by Nigel Gilbert and Michael Mulkay (1984). ASD considers scientists' texts and talk as activities in need of explanation rather than resources for explanation. As a result, I analysed the patterns, discursive strategies and storylines of the naturally occurring talk I generated from the qualitative interviews with the UK and European particle physicists, and with the staff members of CERN, the European Organization for Nuclear Research. Moreover, I compared the discursive characteristics of the naturally occurring talk with that of the working documents of the European Strategy for Particle Physics (2006, 2013).

I argue that the discursive pattern presented when justifying the value and importance of particle and high-energy physics indicates a hierarchy of interests among the European particle physics community. Despite explaining the impacts and societal benefits of their research, the data sources (documents and interviewees) constantly emphasised the curiosity-driven purpose of research. Moreover, this emphasis on the non-applied purpose of research is justified by the commonplace narrative arc about the linear impact of 'basic research' on technology, economy and innovation. Nevertheless, the contents of the narrative arc are seldom supported by the interviewees' or the authors' direct experience in delivering these impacts. When the staff-members of CERN were asked to reflect on their policy-related practices at CERN, they tended to disagree with particle physicists about the efficiency and productivity of the non-applied purpose of research for delivering impacts.

In other words, the linear impact of particle and high-energy physics research is more of a strategic representation of the research community than a common reflection of the community members on their practices and experiences. I suggest that the findings of this thesis can provide an alternative perspective on the dilemma of evaluating particle physics research as well as other curiosity-driven research. Based on the constructivist account, I regard value as more than an objectively evaluated economic variable. That is to say, value results from continuous social interactions and can therefore be studied as discourse and action. In the context of this thesis in particular, I have found that pragmatic policy expectations have become a space that the curiosity-driven particle and high-energy physics community tend to practise and discourse on when responding to questions about the value of its research. To date, there has been no systematic evaluation of the curiosity-driven research community's discursive response to policy agendas on impact and social responsibility. Therefore, the findings of this thesis—that the discursive arrangement of the particle physics community prioritises its community's epistemic values over the public interest when communicating outward—addresses a gap in the Science Policy Studies and Science and Technology Studies literature.

Lay Summary

The discovery of the Higgs boson at CERN (the European Organization for Nuclear Research) during 2012 and 2013 caused a media frenzy, particularly in the West, where curiosity-driven physics commands considerable and enduring prestige. However, given that the member and associate states of CERN contributed over ten billion pounds to the search for the Higgs boson, my question in this thesis is: 'how do we account for the worth or social value of particle and high-energy physics research?'. As social value requires justification and negotiation, my research focuses on 'discourse'. I am particularly interested in comparing ways in which the value and importance of particle physics are explained and the reasoning underpinning these accounts.

In this study, I have unpicked the ways in which different groups of people within particle physics community speak about the value of their investigations. These groups have different perspectives on, and engagement with current policy agendas relating to impact and social responsibility. However, there is a shared discursive pattern within the research community: a tendency to prioritise the community's belief in knowledge over public interest. I have determined that the discursive patterns presented when the value and importance of particle and high-energy physics are being justified indicate a hierarchy of interests. In this hierarchy, emphasis is placed on the curiosity-driven purpose of research.

The discourse justifying the particle physics community's hierarchy of interests also demonstrates the insufficiency of this preference of pure knowledge in terms

of the wider value of particle physics. Furthermore, although the language patterns used by CERN knowledge transfer personnel also display the influence of this hierarchy, when asked to reflect on their knowledge transfer experiences they struggled to defend the efficiency and productivity of their activities. Therefore, I conclude, the hierarchy of interests represented in the discourse I studied requires us to consider the obstacles such a construction might lead to when investigating the social value of particle physics.

I believe that my research on the discursive practices of members of the particle physics community provides a social perspective for the general public to rethink the value and importance of curiosity-driven research.

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List of Acronyms

ASD–Analysis of Scientific Discourse

BSM–Beyond the Standard Model of Particle Physics

CERN–European Organization for Nuclear Research

CPI–Converging Partial Indicators

CP Violation–Charge Parity Violation

DESY–Deutsches Elektronen-Synchrotron

EIDA–Ethnomethodologically-inspired Discourse Analysis

Fermilab–Fermi National Accelerator Laboratory

HEP–High-Energy Physics

KT–Knowledge Transfer

LHC–Large Hadron Collider

Linear Model–Linear Model of Innovation

NPM–New Public Management

QM–Quantum Mechanics

REF–Research Excellence Framework

RRI–Responsible Research and Innovation

SM–Standard Model of Particle Physics

SPRU–Science Policy Research Unit

SPS–Science Policy Studies

SSC–Superconducting Super Collider

SSK–Sociology of Scientific Knowledge

STFC–Science and Technology Facilities Council

STS–Science and Technology Studies

SUPA–Scottish Universities Physics Alliances

TeV–Teraelectronvolt

The Strategy–European Strategy for Particle Physics

TT–Technology Transfer

TWOD– 'Truth Will Out' Device

UoE–University of Edinburgh

WWII–The Second World War

WWW–World Wide Web

Chapter 1 Introduction

The Higgs Boson and Its Perceived Worth

1.1 Discovery of the Higgs Boson

The discovery of the Higgs boson is both a scientific incident and a cultural phenomenon throughout Western societies. Not only did the experiment take place inside the 27 kilometres of tunnel 175 metres under the French-Swiss border, the phenomenon has the momentum and mobility to travel beyond the laboratory into society and politics. Learning more about this immensely significant scientific discovery, I became particularly interested in how its value and importance are articulated and constructed by members of the particle physics community in social interactions.

Human beings have yet to understand the origins of the physical world. Physicists around the world constantly strive to solve this enduring puzzle through such techniques as celestial observation, outer space exploration, cosmic radiation detection and highly technological underground particle experimentation. The discovery of the Higgs boson in an underground high-energy physics (HEP) experiment by CERN, the European Organization for Nuclear Research, announced in 2012 and confirmed in 2013, has provided the particle physics and HEP community with global media attention (CERN, 2012, O'Luanaigh, 2013). The Higgs boson is the key prediction of the Standard Model of Particle Physics (SM)[1]

[1] The mainstream theoretical framework of particle physics that explains the foundation

that attempts to answer how the origins of the physical world attained mass from energy through quantum excitation of the Higgs field. To be more specific, the Higgs particle is a crucial mechanism in the unified theory of the SM, which explains how massive particles such as the W and Z bosons attain their mass from massless protons (Slezak, 2013). Although the existence of the Higgs boson was proposed during the 1960s by several particle physicists, including Peter Higgs and François Englert, it was the final unverified factor in the SM for over half a decade.

Since the discovery of the W and Z bosons in the 1980s, particle physicists have stressed the importance of investing in the Higgs boson experiment to policymakers and the general public, with articles by John Ellis and other particle physicists promoting this work and construction of the Large Hadron Collider (LHC) regularly appearing in the journal *Nature* (e.g. Ellis, 1994); in 2012, the Director-General of CERN shouted: *'I think we have it!'* (Nature Physics, 2012: 575), with Peter Higgs sitting in the audience, bathed in thunderous applause and moved to tears (Waugh and Macrae, 2012); and in the press release for the Nobel Prize in Physics for 2013, the exclamation *'Here, at last!'* (Nobelprize.org, 2013: 1) was made to express the importance of experimental verification of the Higgs boson theory. The media has compared detection of the Higgs boson to determination of the DNA structure and the Apollo Moon landings (Connor, 2012), and nicknamed

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of the universe through interactions between fundamental particles and four fundamental forces: gravity, the weak, the electromagnetic and the strong forces: CERN. n. d.-b. *The Standard Model* [Online]. Geneva, Switzerland: CERN. Available: https://home.cern/about/physics/standard-model [Accessed 17 June 2018].

the Higgs boson 'the God particle'[2] and 'the holy grail of modern physics' (Krauss, 2012). Peter Higgs has become a British and Scottish hero, receiving the 2013 Nobel Prize in Physics alongside François Englert (Stjernlöf, 2013). On the day of CERN's initial announcement, UK Prime Minister, David Cameron, officially acknowledged Higgs' contribution: *'Let's not forget that this discovery started right here in Britain. The man behind the theory, Peter Higgs, was born and bred in Newcastle and did his ground-breaking work in Edinburgh'* (STFC, 2012: 1).

I had my first direct experience of 'Higgsteria' (Farmelo, 2014) in 2013, the year I arrived in Edinburgh to start my Master's research programme in Science and Technology Studies (STS). On the eighth of October, 2013, in a lecture for the course 'Science, Knowledge and Expertise', course convenor Dr Jane Calvert began as usual by encouraging students to discuss the scientific news of the day. 'We've got the news today that Professor Peter Higgs from our university will be awarded the Nobel Prize in Physics because of the experimental confirmation of the Higgs boson at CERN', said one of my colleagues. The seminar room then buzzed with our discussion on the Higgs boson. Over the following days, I was continuously bombarded by information about Peter Higgs and the Higgs boson: The University of Edinburgh (UoE) held a press conference to announce its link with Peter Higgs and CERN; the UoE public outreach teams and Edinburgh International Science Festival organised several events with Peter Higgs in attendance; and exhibitions and public lectures explaining the discovery of the Higgs boson to the

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[2] This nickname originated in the title of a popular particle physics book co-written by a Nobel physics laureate. See: LEDERMAN, L. M. & TERESI, D. 1993. *The God Particle: If the Universe is the Answer, what is the Question?,* New York, New York, Dell Publishing .

general public were held at the National Museum of Scotland and other museums throughout the UK. These experiences were very different from my first impression of the Higgs boson in Taiwan a year previously; '上帝粒子' (the God particle in traditional Chinese characters) was discussed by only a few of my Taiwanese physicist friends and granted little media coverage. As a result, while particle physicists probe the origins of the physical world, my curiosity has been piqued by the social world particle physicists have mobilised and interact within.

I am particularly interested in the entangled relationship between particle physics and the political and economic environment in which it is embedded. Particle physics, also known as HEP, is regarded as a 'big science', a term/concept used by American nuclear physicist Alvin Weinberg in the sixties to describe large-scale science: that which according to Weinberg is as great as the pyramids and the Palace of Versailles (Weinberg, 1961: 5). Because of its scale, big science normally *'cannot survive in isolation from the non-scientific spheres of society',* and *'has become an economic, political, and sociological entity in its own right'* (Galison and Hevly, 1992: 17). The scientific reason that particle physics is a big science is based on the equivalence of mass and energy in modern physics – $E = mc^2$ – which also accounts for the binding energy of forces holding nuclei together (Fernflores, 2012, Spencer et al., 2016): therefore the detection of subatomic particles requires high energies to divide atoms and nuclei. Hence, HEP experimentation is the key approach to verifying the theoretical predictions of particle physics[3], and demands huge experimental facilities that require tremendous amounts of time,

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[3] Alongside cosmic-ray detection, the collection of traces of subatomic particles resulting from high-energy activities in the Universe.

money, resources and human labour. The European member and other associate states of CERN contributed more than ten billion pounds to the search for the Higgs boson (Knapp, 2012), and thousands of international scientists and experts spent over twenty years planning and constructing the LHC—the biggest (27 kilometres in circumference and 175 metres below the ground) and the most powerful (up to 13 teraelectronvolts[4]) particle accelerator ever built[5].

Hence, I believe that not only the 'trustworthiness' of particle physics knowledge but also its 'worth' requires scrutiny. The main question of my thesis is therefore 'how do we account for the worth of particle and high-energy physics research?' Moreover, I regard 'worth' or 'value' as something more than an economic variable determined from external standards and more than the perception of a single individual: I consider 'value' or 'worth' to result from continuous social interactions, made available for analysis through discourse and action. In other words, this thesis does not attempt to define what the value of science is, but focuses on actors' responses to questions about the value or worth of particle physics, and their justifications for supporting particle physics research within the contemporary science policy context and society in general. I will also reflect on how these justifications affect or reinforce the culture of scientific research. In brief, this thesis is theoretically informed by literature from science and technology studies (STS) and science policy studies (SPS), particularly relating to science-

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[4] Tera is a unit prefix in the metric system denoting multiplication by 10^{12} or 1000000000000; Teraelectronvolt is abbreviated to 'TeV'.

[5] More information about the LHC can be found at: *The Large Hadron Collider* [Online]. Geneva, Switzerland: CERN. Available: https://home.cern/topics/large-hadron-collider [Accessed 28 May 2018].

policy interplay and the social relations of science, and is methodologically inspired by ethnomethodology and constructivist discourse analysis as practised within the sociology of science. Following a brief description in this chapter, I will present a more detailed explanation of the theoretical and methodological framework in which this study is grounded in Chapters 2 and 3. This thesis is empirically based on qualitative studies of primary data from interviews and secondary data from policy documents and scientific outreach material. I believe that the approach I applied has enabled me to determine the patterned characteristics of discourse on the value or worth of particle and high-energy physics, which indicate a common attitude among members of the European particle physics community towards contemporary science-policy agendas and external expectations, a subject area which has previously undergone no systematic evaluation.

1.2 A Brief History of Big Physics

CERN is an international basic physics research institution that has more than sixty years of history. The LHC not only enables control of the speed and direction of particles but as the preeminent HEP experimental facility in the world also attracts particle physicists from across the globe. There are other HEP facilities, including Fermi National Accelerator Laboratory (Fermilab) and SLAC National Accelerator Laboratory in the United States, Deutsches Elektronen-Synchrotron (DESY) in Germany, Budker Institute of Nuclear Physics (BINP) in Russia, the High Energy Accelerator Research Organization (KEK) in Japan, and the Institute of High Energy Physics (IHEP) in China. With the LHC, however, CERN has dominated the high-energy research frontier of particle accelerators, prompting those in charge of other accelerators to focus on neutrino physics programmes and high-intensity research requiring lower energy levels, which still contributes to the experimental results of high-energy research (NSAC, 2008). In other words, the leading status of CERN has created a cluster effect in the international HEP community and has a huge impact on the ecology of European particle physics research. For instance, between 2011 and 2015, the Science and Technology Facilities Council (STFC) in the UK planned to spend over sixty percent of its budget on particle physics research by investing in CERN (House of Commons Science and Technology Committee, 2011: Ev 49)

Europe has not always been at the frontier of big physics research, having lagged behind the U.S., which entered into nuclear research with the Manhattan Project launched during World War Two (WWII). It was in the common interest of European countries to revive their scientific, economic and political standing after the war. International science advisors, such as the American Nobel Physics Laureate, Isidor Isaac Rabi, considered the founding of a European big physics project as a way of restoring the international competitiveness of European countries (Hermann et al., 1987: 11–13). The full name of CERN – the European Organization for Nuclear Research – reflects this historical context. At the time CERN was established, the term 'nuclear science' [6] had two connotations: elementary physics research was focused on the atomic nucleus, but this term

[6] Along with the rise of the SM in the early seventies, the popularisation of the term/concept, 'particle physics', evolved gradually out of 'nuclear science'. Nowadays, CERN states that its main focus is on particle physics rather than nuclear science. See: CERN. n. d.-a. *About CERN* [Online]. Geneva, Switzerland: CERN. Available: https://home.cern/about [Accessed 4 June 2018].

hinted at the possibility that CERN could be as influential as the Manhattan project. Nevertheless, having witnessed the lethal effect of atomic bombs, European nuclear physicists were against the political and military purpose of that research and expected CERN to be a haven for pure scientific enquiry (Pestre and Krige, 1992: 79–83). The European nuclear physics project is thus different from those of the United States and the former Soviet Union, both fuelled by the scientific and technological competition of the Cold War[7].

While science and technology offer new possibilities they also pose new threats. Therefore, scientists and their communicators attempt to 'convince the public of either the intellectual grandeur or the practical significance of scientific research', as observed by STS scholar Alan Irwin (1995: ix). The scope of this thesis is how this is carried out within particle and high-energy physics, a particularly expensive area of research. The scale and expense of the HEP experiment required the member states of CERN[8] to contribute a certain proportion of their annual gross domestic product (GDP), which is not common in other scientific disciplines. As a result, although this pure elementary physics research may appear esoteric to the general public, it ~~still~~ has to confront the public's ideas of financial or material value. For example, at a European Conference in 1949, Raoul Dautry, one of the

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[7] Japan and China have also invested in HEP research after WWII. Moreover, the work of Japanese particle physicist Yoichiro Nambu inspired Peter Higgs and other physicists to study the Higgs mechanism. Nevertheless, the historiographies I have referred to in this thesis hardly mention the Japanese and Chinese particle physics communities, and therefore I am not able to investigate the social context of Asian particle and high-energy physics research in detail.

[8] The historical involvement and current member states of CERN can be found at this webpage: https://home.cern/about/member-states.

founding fathers of CERN and an engineer, politician and business leader, described his vision of the future European institute not as a place for fundamental research but somewhere work could be *'directed toward applications in everyday life'* (Pestre and Krige, 1992: 79). Another founder has defined CERN as *'a training ground for technical experts who might then work on military or industrial applications of nuclear energy'* (Heilbron, 2003: 136). In other words, despite European nuclear or particle physicists not intending to contribute to the military, the successful wartime collaboration between physics research and the armed forces still opened the imagination of decision-makers to the value or worth of fundamental physics research (Hermann et al., 1987: 11–13). These historical episodes imply that, since the beginning of CERN, those at the strategic higher-level of CERN have had multiple and pragmatic expectations.

Before the war, the founding father of the first major American particle accelerator in the University of California at Berkeley, nuclear scientist Ernest Orlando Lawrence, also had to persuade people of the wider benefits of HEP research. To secure financial support for his laboratory, Lawrence had publicised the medical applications of HEP research, and claimed that knowledge gained from HEP experiments would be *'the beginning of an economic revolution'* and *'worth more than gold'* (Traweek, 1988: 3). The wartime Manhattan Project already had a medical section in the Manhattan Engineering District, responsible not only for the health and safety issues relating to nuclear weapons but also the clinical utility and commercial profitability of the radioisotopes produced in nuclear research. The most famous Chief of this medical section, Stafford Leak Warren, was a pioneer in the field of nuclear medicine before joining the Manhattan Project, and the key player in fulfilling the national mission to build a clinical infrastructure for nuclear medicine in the U.S. – the Veterans Administration hospitals – after the war (Lenoir and Hays, 2000: 40). Therefore, from the American wartime history of big science, we can observe that establishing the worth and usefulness of fundamental research relies on considerable social construction.

However, in the recent history of American HEP research, the mobilisation of big physics infrastructures has not been successful, preventing the U.S. from building the high-energy apparatus capable of directly detecting the Higgs boson. In 1993, due to budget problems, U.S. Congress cancelled the construction of a Superconducting Super Collider (SSC) near Waxahachie in Texas. If the construction had continued, the SSC, with its planned ring circumference of 87.1 kilometres and energy of 20 TeV per proton, would have greatly surpassed the capacity of the LHC (Brian, 1993, Hallonsten, 2015). Since then, many American particle physicists and instrumental developers have turned to CERN to pursue research into the Higgs boson. This setback for the American particle physics community demonstrates that political and financial support for big physics research in the U.S. is not unlimited or unconditional. For example, in a debate on the SSC project in the U.S. House of Representatives, even though congressman Jim Slattery stated, *'I strongly support continued, increased funding for our nation's broadly-based scientific research programs'* (C-SPAN, 1993)[9], he considered the expenses of the SSC as *'unnecessary'* and *'excessive'.* Given that costs had been *'uncontrolled'* Slattery proposed the SSC project be cancelled

[9] This reference refers to a multimedia resource and therefore a page number cannot be given.

(Ibid.). Furthermore, in addition to budget and project-management considerations, a number of other congressmen, including Jerry Lewis and Peter Hoagland, questioned the possible contributions HEP research could make to nuclear medicine, claiming direct investment into radiotherapy and magnetic imaging, for instance, would very likely be more cost-effective than waiting for useful by-products of HEP research (Ibid.).

As a result, for generations with little first-hand experience of the Cold War nuclear arms race, the rationale behind costly HEP research – at least in the U.S. – has become less and less persuasive. Early signs of the Higgs boson had been detected by Tevatron, the world's second highest energy particle collider, operated by Fermilab in Illinois: Tevatron was shut down in 2011, reflecting the funding environment that surrounds the American particle and high-energy physics community (Reich, 2011: 1). Investment in CERN has also been questioned. For instance, in the early eighties, UK Prime Minister Margaret Thatcher was concerned about national spending on the Large Electron-Positron Collider at CERN and requested that CERN and particle physicists monitor the efficiency of their research (Randle-Conde, 2013: 2–3); following the 2008 financial crisis, CERN was faced with budget cuts (Macinnis, 2010: 1–2); and even after detection of the Higgs boson, funding for CERN was still under threat when part of the science budget of Horizon 2020 (the European framework programme for science funding) was moved to a new economic-stimulus initiative (Heuer, 2015: 1–2, Stafford, 2015: 1–2).

1.3 The Worth of Particle Physics Research

The history of big physics suggests the balance between the 'understanding' and the 'utility' of knowledge enquiry are constantly under consideration. During wartime, due to the military technologies anticipated, the practical use and the epistemic understanding of elementary physics research were closely aligned. In post-war times, the use and understanding of big physics research are in tension, or at least in need of reinterpretation as, on the whole, scientists wish to be free from the military and political aims that affected science funding during wartime. At other times, such as after the Cold War or in economic recessions, the pure understanding of physics research can be challenged when investment is not deemed to be practical. In different social, economic and political conditions, therefore, interpretations of the 'value and importance' of big physics and HEP research vary from time to time, place to place. Hence, given the cost of HEP experimentation and the highly abstract nature of particle physics knowledge, justifying the worth of particle physics research is an enduring challenge for the science policy community.

Even detection of the Higgs boson could not solve this conundrum since the completed SM theory only explains 5% of the Universe's composition (because of dark energy and dark matter) (Woithe et al., 2017: 52), and particle physicists continue to call for investment into future accelerator technologies to *'find something unexpected'*, *'make big, unknown discoveries'* and *'break physics'* (Webb, 2015a: 1, 2015b: 1). Alongside study of the SM Higgs boson, theoretical particle physicists such as CERN theorist John Ellis are already considering alternative ways of resolving the issue, such as flavour physics (the species of an elementary particle), theory unification and quantum gravity. Theories that go beyond the Standard Model of Particle Physics (BSM), such as supersymmetry and the String Theory, take more variables into account and require testing by HEP experimentation at the TeV scale (e.g. Ellis, 2009).

Furthermore, particle physicists' expectations for more public funding now encounter the trend within public policy of prioritising evidence and efficiency, such as the funding preferences of Margaret Thatcher's government mentioned above. Prime Minister Thatcher's pursuit of a technocratic policy for public-funded science was deemed by STS and SPS researchers to indicate a governmental desire for greater control over public-funded research in the context of a declining UK economy (e.g. Williams, 1988, Edgerton and Hughes, 1989). Although legitimate concerns were raised in these studies about decreases in both academic freedom (Edgerton and Hughes, 1989: 419) and science funding (Williams, 1988: 140), this policy shift did create the grounds for technocratic policy or 'science for policy'[10]. For instance, the first major review of the UK science and technology scene took place in 1981 and a Science and Technology

[10] Since Harvey Brooks published a book about 'science for public policy' (Brooks, 1987), science policy scholars have categorised science policy studies into two branches: 'Science for policy' and 'policy for science'. The former refers to scientific evidence and advice that play a role in the formulation of policy and decision-making; the latter refers to the governance and allocation of resources for the conduct of science in the public interest. See more in: BROOKS, H. 1987. *Science for public policy,* UK, Oxford, Pergamon Press. And chapter 7 in FEALING, K. H., LANE, J., SHIPP, S. & MARBURGER III, J. H. (eds.) 2011. *The Science of Science Policy: A Handbook,* Stanford, California: Stanford Business Books.

Assessment Office was created within the Cabinet Office in 1986 (Williams, 1988: 135–137). Furthermore, following the shift in UK politics during the late 1990s, Prime Minister Tony Blair, although relatively more generous towards the science budget, continued in the technocratic policy direction, calling for a culture that values a pragmatic, evidence-based approach to policy, emphasising the economic relevance and social benefits of scientific research and promoting research assessment exercises and empirically-based foresight programmes (n. a., 2002: 1–8)[11].

This trend has been theorised by the public policy research community (e.g. Barzelay and Armajani, 1992, Elzinga and Jamison, 1995) and labelled 'New Public Management' (NPM) (e.g. Hood, 1995, Lane, 2000, Barzelay, 2001). Since the turn of the century, NPM has developed into an 'impact agenda' in the UK and Europe, in which the evaluation and monitoring systems of research policy, such as the 'Research Excellence Framework' (REF) in the UK (evolved from the previous Research Assessment Exercise implemented by the UK higher education funding bodies, HEFCE) and the EU's Framework Programme (currently known as the Horizon 2020 programme), which assess systematically the quality

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[11] As the empirical research of this thesis focuses on the UK and European particle physics research, I have chosen to contextualise the UK politics surrounding public-funded scientific research, which, through European research collaborations, is interconnected with the European science-policy environment. However, in the U.S., science advisors to President George Bush Jr. (John Marburger III) and President Barack Obama (John Holdren) also emphasised evidence-based science-policy making and public accountability. See p. 319 in: ELZINGA, A. 2010. New Public Management, science policy and the orchestration of university research- academic science the loser. *The Journal for Transdisciplinary Research in Southern Africa,* 6, 307–332.

of academic research (REF, 2011, 2017, EC, n. d.-a). For instance, according to guidelines on the UK Research and Innovation website, Research Councils UK defines impact as *'the demonstrable contribution that excellent research makes to society and the economy'*, and categorises the 'pathways to impact' into 1) academic; 2) economic; 3) societal impacts. Researchers are encouraged to 1) identify and engage users of research and stakeholders; 2) meet the needs or impact upon understandings of stakeholders' needs; 3) think of research in the context of two-way engagement not just outreach (n. a., n. d.). One way in which this is operationalised is through the requirement for all researchers to demonstrate planned 'pathways to impact' as part of the grant application process. For example, the 'Responsible Research and Innovation' (RRI) agenda emphasises the importance of social responsibilities, positive and active science-society interactions (EC, 2014), and the management of contemporary societal issues, such as health and ageing, sustainability within the environment and economy, food security, the use of intelligent technology and the equality of citizens (EC, n. d.-b, UKRI, n. d., NSF, 2017). Interconnecting with this policy trend that plans the future landscape of scientific research for the benefit of external stakeholders, SPS scholars have proposed several visions for the sustainable development of science, technology and innovation, including 'Mode 2' knowledge production (Gibbons et al., 1994, Nowotny et al., 2003), 'post-academic' science in a 'dynamic steady state' (Ziman, 1994, 2000), the 'Triple Helix' of university-industry-government relations (Etzkowitz and Leydesdorff, 2000) and the 'co-production' of knowledge (Jasanoff, 2004) (more discussions in section 2.2: **p. 56**).

Reliance on public funding has made substantiating the value or worth of particle physics and HEP research imperative within the current pragmatic science policy culture. In the case of CERN, although the obligatory financial contributions from member states are regulated by a convention established over half a century ago (CERN, 1971), since 2006 the CERN Council has planned and updated the *European Strategy for Particle Physics* (the Strategy) (2006, 2013)[12], which not only defines the research priorities of the European particle physics community but is concerned with the wider impact and social responsibilities of its research; one third of the strategic goals relate to wider non-scientific activities (read more in sub-section 3.3.3: p. 108). In addition, the CERN Courier states that implementation of the Strategy is to *'ensure that Europe stays at the forefront of particle physics research, which pays dividends in terms of knowledge, innovation, education and training'* (n. a., 2013: 1). This is not a mere discursive practice of the European particle physics community in response to the pragmatic science policy agenda; the Strategy has changed the organisational structure of CERN. In between release of the two versions of the Strategy, the Technology Transfer group at CERN (CERN TT), previously responsible for managing issues relating to 'the diffusion of technological products from universities and government laboratories'—the understanding of 'technology transfer' in general use since the 1980s (Bozeman, 2000: 627)—has been expanded and rebranded into the *Knowledge Transfer Group* (CERN KT). Nowadays, CERN KT not only deals with patenting and the intellectual property rights of CERN's technologies but acts proactively to plan and realise the wider practical impact of particle and high-

[12] The 2020 update of the Strategy is undergoing and not yet finalised. For more information, see: N. A. 2018. Call for input to European strategy update. *CERN Courier*.

energy physics research. During the Strategy updating process between 2012 and 2013, CERN KT was responsible for researching and planning in advance the social benefits of particle physics. However, although ‘knowledge transfer’ is a new branding and practice introduced by the earlier CERN TT after the millennium, the concept of knowledge transfer or translation emerged in the 1990s and implies that knowledge is pushed by the producers of research to the users of research through a one-way interaction between the research community and society or industry. More recently, the concept of ‘knowledge exchange’ has emerged, calling for more interaction between researchers, decision-makers and other stakeholders. Mechanisms such as the use of intermediaries that understand both roles – known as ‘knowledge brokers’ – have therefore been proposed and experimented with (Mitton et al., 2007: 729–768). It will be interesting to see whether or not the forthcoming Strategy update in 2020 will contain the element of ‘knowledge exchange’.

In parallel with the NPM trend in science policy, the SPS community, especially the strand researching ‘policy for science’, has proposed systematically evaluating the performance of particle and high-energy physics research (e.g. Martin and Irvine, 1981, 1983, 1984a, 1984b, 1985, Irvine and Martin, 1984a, 1985) (more discussions in section 2.3: p. 63). These early works on research evaluation have inspired the development of a wider assessment framework that includes bibliometrics, citation analysis, as well as journal and university rankings with regard to different scientific disciplines (e.g. Ramsden, 1994, Cave, 1997, Leydesdorff, 1998, 2001, Moed, 2005). Nonetheless, because of the low predictability and unclear applications of elementary physics research, evidence-based research evaluation encounters difficulties assessing the wider value and importance of this type of research. Furthermore, it has encountered criticism within social and historical studies of science and from the SPS community for being insensitive to the context-dependency of the worth and status of science (e.g. Collins, 1985b, Krige and Pestre, 1985, Martin and Irvine, 1985, Hicks, 1992, Pavitt, 1997) (more discussions in section 2.3: p. 63). As a result, subsequent policy studies have suggested considering the 'ex-post' (after the fact) impact of physics research, the non-information forms of research output, such as societal and cultural benefits, and the productivity of physics research facilities (e.g. Martin et al., 1996, Kanninen and Lemola, 2006, Wakeham, 2008, Science-Metrix, 2014, Hallonsten, 2016). With energetic discussions and studies of the practices and influences of research evaluation (more discussions in section 2.3: p. 63), the science policy and SPS community has evolved to take both quantitative, generalised indicators and qualitative, peer-reviewed information on the worth of elementary physics research into account.

I believe that these constant interactions between the scientific community, the policy community and the policy studies community become cultures, expectations and possibly even rules, in which representations and interpretations of the value and importance of particle physics and other elementary physics research are articulated. I have noticed there is a discursive 'space' in which actors attempt to make sense of the value and importance of particle physics and HEP research. Moreover, in this space, words, texts and language-use carry or embody the value or worth of particle physics research, enabling the negotiation, translation and transformation of scientific value between various interests and expectations.

Therefore, in order to study the interactions of the particle physics community with the wider social, political and economic context, and the tensions between the understanding and utility of research, I suggest following and studying the production and circulation of value claims. After all, without articulation, interpretation and communication, knowledge, particles, accelerators, values and impact cannot be collectively understood and realised by human beings. However, a constructivist angle—which would focus on the construction and reconstruction of 'value'—has yet to be adopted by the majority of SPS scholars. In the following section, I introduce constructivist studies of knowledge and status construction within the physics community from STS literature.

1.4 Integrating SPS and STS: Everyday Constructions of 'Worth'

I argue that the omission of a constructivist angle in SPS literature is unjustifiable, since the science policy community also needs a way to understand, beyond face value, the language and practices of scientists. Since popularisation of the physics community has a long history in Western societies (e.g. Stewart, 1992, Pang, 2002, Marché, 2005, Knight, 2006, Riskin, 2008, Papanelopoulou et al., 2009), the everyday construction and reconstruction of the value and importance of physics research has been practised beyond the research community, and particle physicists still play a pivotal communicative role in the everyday construction of 'value'. For instance, famous particle physicists, such as Peter Higgs, John Ellis and Brian Cox, talk to lay audiences not only about scientific implications but the wider importance of their research (e.g. TED, 2008, 2012, 2015, 2016, BOLDtalks, 2013, The University of Edinburgh, 2013, Yeh, 2013), and author popular books that contain both scientific explanations and political messages to justify the worth of HEP research (e.g. Fraser, 1997, Lincoln, 2014, Butterworth, 2014, 2016, Gagnon, 2016, Gianotti, 2016). In other words, they are the missionaries of particle physics, seeking support by sharing the purpose of their scientific journey, their experiences and predictions.

In STS, scholars have reflected on science popularisation initiatives, for instance, the Committee for Public Understanding of Science (COPUS) created in the UK in the mid-1980s, particularly in relation to the 'deficit model' concept: a presumption that a more 'scientifically literate' public and a more supportive or enthusiastic attitude towards scientific and technological developments can be cultivated by scientists' wider communications or so-called 'public outreach', a traditional way of describing cross-boundary practices initiated by the scientific community. STS researchers have demonstrated concern about the imbalanced power-relationship between science and society and the one-sided knowledge and value claims constructed by the practice of science communication or public outreach (e.g. Wynne, 1992, Irwin and Wynne, 1996, Dierkes and von Grote, 2000). Consequently, both social scientists and the science-policy community have proposed the importance of the concept and practice of 'public engagement', intended to open up science and its governance not only to scientists themselves but to every stakeholder (e.g. Stilgoe et al., 2014, RCUK, n. d.-b). Following the emphasis of the UK impact agenda in the 21st century, the term/concept 'public engagement', which encourages two-way interactions between science and society, is increasingly used (RCUK, n. d.-a).

Hence, I propose that the language and practices used to substantiate the value and importance of particle and high-energy physics research are in need of systematic analysis. The construction of knowledge and representation of the physics community have always been central topics within STS (e.g. Collins, 1981, 2001, 2004, Pickering, 1984, Pinch, 1985, Shapin and Shaffer, 1985, Traweek, 1988, Galison, 1997, Knorr-Cetina, 1999, Doing, 2009, Reyes-Galindo, 2014) (more discussions in section 2.4: p. 69). In contrast to the studies of the social history of physics (e.g. Forman, 1971, 1987, Kaiser, 2002, 2005, Hallonsten, 2015), these STS works investigate the internal process of knowledge production, in which physicists dispute the validity or credibility of their knowledge claims. Moreover, anthropological and laboratory studies of the physics community have closely scrutinised physicists' collective production and construction of facts and knowledge. Examples include the studies by sociologist of gravitational-wave physics Harry Collins (2004), anthropologist of particle physics Sharon Traweek (1988) and sociologist of big physics and big biology Knorr-Cetina. Although the methodology of these studies echo the starting point of this thesis, they focus more on the internal relations of research communities (more discussion on this in section 2.4: p. 69). My direct experience of the frenzy surrounding discovery of the Higgs boson has inspired me to pay close attention to how the value and importance of particle physics are accounted for in everyday interactions. In the context that complex political and economic conditions are required for the development of particle and high-energy physics research, the study of particle physicists' value propositions has to also consider their dynamic interactions with external actors.

To clarify, in this thesis, I do not intend to reconstruct my own version of the value and importance of particle physics: my interest lies in the interpretative flexibility and changing social construction of value claims made by members of the particle physics community in response to the queries of non-members. Having experienced so many versions of the value of particle and high-energy physics research in the cultural phenomenon of the Higgs boson, in historical texts and in research evaluations, my aim is to explain the context that allows a multiplicity of often competing value interpretations to co-exist. In no way do I argue that particle physics holds no real value, only representations: rather, my concern is that neither an individual researcher, including myself, nor a single community can propose a complete view of the worth of science. Furthermore, particle physicists, at least in the UK, now systematically practise outreach activities in order to evidence their impact through the pathway of public engagement (e.g. UCL, n. d., REF, 2014). I consider it important for the SPS community to focus on the interactive practices and value claims made for particle and high-energy physics research. However, the analytic angle of SPS literature, especially on the evaluation or assessment of physics research, is often restricted to the institutional level that studies measurements or categories, and neglects the opinions and practices of individual scientists.

In the body of SPS, STS and history of science literature, studies have been carried out that focus on how the status and authority of 'basic research' or 'big science' is constructed at the nexus of science, policy and society (e.g. Gieryn, 1983, Galison and Hevly, 1992, Mulkay, 1993, Stokes, 1997, Rip, 2000, Edgerton, 2004, Calvert, 2006, Godin, 2006, Pielke Jr, 2012) (more discussions in sections

2.2 and 2.4: p. 56 and p. 69). Moreover, western scientific research has inherited the ideal of pure inquiry from the ancient Greeks (Stokes, 1997: 26). Therefore, I suggest we should be aware of the cultural influence of the constructions of basic research and big science in the language and practices relating to the value of particle physics. While SPS research normally has a pragmatic aim that encourages the development of scientific and technical research and exploits the results of this research for general political objectives (Elzinga and Jamison, 1995: 575), I hope that my constructivist approach to studying the value or worth of particle physics research can provide an alternative perspective on research evaluation and assessment. That is, an understanding of value cannot be separated from the everyday context where the value is constructed, and the study of value has to consider and critically examine the cultural resources actors utilise.

The focus of this thesis is neither outcome assessments of research nor research assessment policy; rather, in this thesis, I pay attention to the interconnection between the values claimed and practised by members of the particle physics community and the cultures of pragmatism in which they are embedded. The objective of this thesis is linked to reflections on the limits of governance in SPS literature (e.g. Lyall et al., 2009) as well as the normative turn in STS literature (e.g. Gibbons et al., 1994, Nowotny et al., 2003, Jasanoff, 2004). Based on the conundrum that the policy community and the scientific community often have different interests, contrary value positions and distinctive cultures that require long-term negotiations, the active participation of policymakers as well as STS and SPS scholars in the making of science, technology and innovation, demands more sociological studies of the interactions and negotiations between these communities. Furthermore, in the present climate, particularly in the UK and Europe, where individual members of the scientific community all have the role and duty to think, articulate and practise policy agendas on impact and social responsibility, I believe a more nuanced understanding of the way members of the scientific community receive, digest and respond to external expectations relating to the value of research is imperative.

Indeed, not only the members of the particle physics community have a role in shaping the value and importance of particle and pure physics research. Thinking reflexively, especially within the trend of co-production or Mode 2 science, members of the SPS and STS community also have a voice in arguing the worth of scientific research. Hence, I need to explain the reason for this thesis focusing particularly on the value claims and constructions of members of the particle physics community. My reasoning relates to my concerns about, and experiences in contemporary public outreach for particle physics in the context of the Higgs boson discovery. From this angle, I argue that the internal community's influence on the perceived value of particle physics continues to outweigh that of the external community. That is to say, the SPS and STS communities have not yet conducted a great deal of external communication with the general public about the value of the Higgs boson. This is why I have chosen not to empirically study the value claims of the community I currently belong to. This does not mean I asymmetrically neglect the value practices of myself and my identity group. However, it does reflect my belief that as particle and high-energy physics are often publicly funded, the impact and social responsibility agenda is necessary. I maintained a reflexive awareness throughout my research, to ensure my personal mind-set was not imposed on my research objects or analysis. Instead, it served as a spur to curiosity, leading me to address how members of the particle physics community justify themselves beyond their scientific boundary. The value constructions of the STS and SPS communities certainly merit investigation in other research projects.

1.5 Outline of Chapters

After this introduction, there are six more chapters in this thesis. The following literature review serves two purposes (chapter 2: from p. 55 on). Firstly, I explore the connection between my interest in the contemporary worth of particle physics research and ongoing studies of, and debates on, the legitimacy of publicly-funded pure enquiry, as well as the similarities and dissimilarities between my research objectives and the evaluation of basic physics research in SPS literature. Secondly, I explain the epistemological inspiration I have derived from STS literature, which facilitates analytic attention on interactions and practices in the constructions and reconstructions of knowledge and value claims. Moreover, I introduce the key literature that has influenced the design of my methodological framework: an ethnomethodologically-inspired, constructivist discourse analysis that focuses on the use of language and discourse in co-producing and making sense of the world.

As a result, the chapter on methodology (chapter 3: from p. 89 on) is developed alongside this epistemological and methodological framework, intended to generate and analyse, through interviews and document collection, ordinary speech and practices related to shaping the value and importance of particle physics research between scientific and policy expectations. I believe that this type of data has not received enough attention from either the STS or SPS communities.

The three empirical chapters that follow the methodology are a step-by-step analysis of the culture of the particle physics community, which interacts with the current orientation of science policy agendas in the UK and Europe. Evidence of this culture that I analyse includes the recurrent discursive patterns I identify in interviews with UK particle physicists (chapter 4: from p. 123 on); the narrative strategy for wider communication deployed by a high-level particle physicist; the European particle physics community's most significant strategic document (chapter 5: from p. 155 on); and the day-to-day interactions with, and experiences within the internal culture of the research community as recounted by CERN officers (chapter 6: from p. 189 on). I will argue in this thesis that, through the methodology I have used, it is possible to generate a systematic understanding of value claims provided by the particle physics community, and approach the opinions and stances of particle physicists that structure this discourse or representation in response to external expectations or mandates. This aspect, as I point out in the literature review, is virtually ignored by the evaluation and assessment tools proposed by the SPS community.

Furthermore, through analysis of the discourses, practices and cultures related to establishing the value and importance of particle physics research within the complex interrelations between science, policy and society, I argue that this thesis has the potential to open up the co-production of research motivations and the culture of curiosity-driven particle and other basic physics communities. 'Curiosity', as discussed by Helga Nowotny, professor of social studies of science, is interrelated with everyone's desire to know the future, to be safe from unwanted surprises, to protect what one already has, and to be able to master the unknown; it motivates us to take the next step that leads beyond familiar terrain. Consequently, the thin line between the present and the future is crossed (Nowotny, 2008: 2–3). In other words, I believe that discursive analysis of the particle physics community's contextual ideas about the value of curiosity-driven research will enable us to understand more about, and engage deeper into, the directions triggered by scientific curiosity, now and in the near future. The insights drawn from my empirical findings and further policy recommendations are discussed in the concluding chapter (chapter 7: from p. 221 on).

Chapter 2 Literature Review

Making Sense of the 'Worthwhileness'[13] *of Science*

2.1 Outline of the Literature Review

As particle physics is generally classified as 'basic research', I begin this literature review by tracing the construction and reconstruction of this term and justifications for its practice. I also clarify the core issue behind the shaping of basic and applied research, the tension between these two objectives: research for the research community itself against research that will benefit wider society (section 2.2). Secondly, I examine the expectations of the science policy community and the means by which they evaluate elementary and particle physics research. I argue that these evaluation policies and tools, which focus on the outcomes of research, are inadequate for examining and taking account of the objectives of particle physics research (section 2.3). Thirdly, therefore, I describe the inspiration I have gained from STS literature, that the study of everyday constructions and interactions can facilitate understanding of why the worth of

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[13] I use this word in this chapter to emphasise the making, fashioning and construction of the worth or value of science. This word-use expresses my constructivist stance that focuses on the interactional practices in the process of making claims, facts and truths. I am aware that in the field of moral economics and theory of knowledge there is a renowned study of the practices of 'justification' in understanding the forms of worth (common good) established in different social worlds: BOLTANSKI, L. & THEVENOT, L. 2006. *On Justification: Economies of Worth,* Princeton, New Jersey, Princeton University Press. However, my interest in and enquiry into the value claims and practices made for particle and high-energy physics research has not been directly influenced by this work.

particle physics is claimed and practised as such at the nexus of science, policy and society (section 2.4). In the final part of the literature review (section 2.5), I introduce the discourse analysis approach, which takes inspiration from the constructivism of STS and the study of 'essence' within ethnomethodology. My aim is to understand the ways in which the particle physics community responds to contemporary science policy culture and research evaluation agendas. With this understanding, we can then examine the credibility of the value claims and practices mobilised within particle physics research as discussed in the subsequent empirical chapters.

2.2 Objectives and Outcomes of Scientific Research

In science policy documents and the SPS literature, we can observe the tension between advancing scientific 'understanding' and promoting the 'utility' of science in the distinction between 'basic research' and 'applied research'. Namely, in modern science policy discourses, the objectives of science are commonly differentiated into two broad categories: the practical intention to apply the outcome of research to everyday life, labelled 'applied research', and the epistemic aim to understand more about the world, labelled 'basic' or 'fundamental research', and known as 'pure science', 'blue-sky research' or 'curiosity-driven research'. Actors in the science policy community are therefore faced with the virtually impossible task of anticipating the wider impacts of basic research. This dual property of science has its roots in certain aspects of the history of Western scientific development. Western scientific research has inherited the ideal of pure inquiry from ancient Greeks, such as the philosophers and mathematicians Pythagoras and Euclid, as well as the atomists Leucippus and Democritus, who introduced the possibility of explaining the nature of matter (Stokes, 1997: 26–28). On the more practical side, firstly, the medieval Italian Renaissance and secularisation of the Christian faith prompted an early practical turn; secondly, the interconnection between the scientific revolution of the 17th century, the industrial revolution in the 18th century, and the rise of experimentalism and instrumentalism during the 19th century have all emphasised the usefulness of knowledge.

Exchanges between the two broad objectives of scientific research reached a peak in the first half of the 20th century, a time when developments were emerging thick and fast, including nuclear energy, rocketry, genetics, cancer treatment and ecology, and scientists were playing a far more significant role during the second world war (WWII) than in the past (Fuller, 2013: 1–2). Science in modern democratic societies is interwoven with political opinions and proponents of both elevating the social contract of science and centrally planned research, including John Desmond Bernal (1939), and of defending scientific freedom and autonomy, such as Michael Polanyi (1940, 1951), have voiced their opinions strongly. It was in this context that the term ‘basic research’ emerged. Vannevar Bush, head of the U.S. Office of Scientific Research and Development during WWII, and the first science advisor to the president following the war, named and advocated ‘basic research’. In his famous and influential report to Franklin D. Roosevelt: *Science, the Endless Frontier* (Bush, 1945), Bush defined ‘basic’ and ‘applied research’:

> Basic research is performed without thought of practical ends. It results in general knowledge and an understanding of nature and its laws. This general knowledge provides the means of answering a large number of

> important practical problems, though it may not give a complete specific answer to any one of them. The function of applied research is to provide such complete answers.
>
> (Bush, 1945: 14)

Without a great deal of evidence, Bush believed that basic research, despite having no inherent practical intent, played an important role in solving practical problems. That is to say, without the knowledge that results from basic research, the long-term usefulness of applied research is not possible. However, compared with applied research, which Bush regarded as the provider of complete answers to practical problems, the role of basic research is relatively ambiguous. In another part of the report, Bush argued that not only did applied research acquire the means of answering practical problems from basic research, but products, processes and enterprises resulted from the novel principles and conceptions of basic research (Bush, 1945: summary). Once again, Bush did not specify what exactly these concepts and standards were. Debates about the robustness of the argument for basic research did take place, in early volumes of the SPS journal *Minerva* during the sixties, for example (e.g. Polanyi, 1962, Rottenberg, 1966, Toulmin, 1967). Nevertheless, the essential and irreplaceable value and importance of basic research constructed in Bush's report did influence science-policy discourses and practices within the U.S. and many other countries around the world. Therefore, the somewhat fuzzy original concept of basic research was stabilised through circulation, documentation and institutionalisation (Pielke Jr, 2010: 923, 2012: 356).

The 'basic research' proposition pioneered by Bush and supported by many scholars (e.g. Polanyi, 1962, Rottenberg, 1966, Toulmin, 1967) emerged after people had witnessed the importance of science during WWII. Post-war scientific research in the U.S. was infused with binary interests: on the one hand, scientists wished to be free from practical considerations, such as military ends; on the other, the Government had limited resources but several practical issues to address, such as disease and unemployment. However, Bush was determined to use significant public funds for pure enquiry, and constructed his storyline of 'basic research' to mitigate the conflict of interests between scientists and politicians. In this storyline, 'basic research' is positioned in a particular role that applied research cannot replace: it can be carried out for curiosity's sake, thereby satisfying scientists, but also meet national needs and keep politicians satisfied. Both the utility and the understanding function of science are woven into the term/concept of 'basic research'. Notwithstanding the assumed ability to advance applied research, the use of this terminology implies a clear separation between curiosity-driven and applied research.

'Basic research' is interconnected with another popular term/concept in the discourse of contemporary science, technology and innovation policy since the fifties: the first version of the 'linear model of innovation' (Linear Model), inspired by basic science (Godin, 2006: 639). The Linear Model explicitly posits a direct relationship between science, technology and innovation; science and the creation of new knowledge are the wellspring of future application and development, which will eventually provide economic benefits (Faulkner and Senker, 1995: 26–27). The Linear Model has been roundly criticised in the SPS literature as an overly simplistic approach to understanding the process of innovation and the influence of science (e.g. Freeman, 1996, Stokes, 1997, Edgerton, 2004, Godin, 2006). In addition, SPS studies have shown that the terms/concepts of ‘basic research’ and ‘Linear Model’ have come together to form an attractive advocate for allowing the pure scientific enquiry to prove its worth in the field of research policy (e.g. Godin, 2006, Pielke Jr, 2012). Taking inspiration from such sources as Actor-Network Theory, the social construction of technology and social learning, the STS literature has also provided a rich picture of the innovation process (e.g. Bijker et al., 1987, Bijker and Law, 1992, Rip et al., 2003). Current ideas, such as ‘open innovation’ and ‘user innovation’ that look beyond the Linear Model, are derived from these STS insights.

In the increasingly competitive world system following the post-war baby boom, pure scientific enquiry has experienced more critical examination from the science policy community, which has called for predictions and evidence of the benefits of research to society (e.g. Freeman et al., 1980, Irvine and Martin, 1984b, Ziman, 1984, Ziman, 1989, Pavitt, 1991, Guston, 2000, Solesbury, 2001, OECD, 2002). This change in the status of basic research can be observed in the declining use of the phrase in *Science* and *Nature* since the early 1990s (Pielke Jr, 2010: 923). The SPS community also began to rethink the rationale behind pure enquiry and its worth. Dividing ‘basic research’ into ‘pure or curiosity oriented research’ and ‘strategic research’, British SPS scholars John Irvine and Ben Martin (Irvine and Martin, 1984b: 3, Martin, 1995: 139) promoted the development of the latter: strategically-directed, long-term research. The American political scientist, Donald Stokes, argued that the government at that time still had a one-dimensional definition of science as either basic or applied, and could not take strategic research into policy consideration (Stokes, 1997: 67). He, therefore, proposed a two-dimensional taxonomy model of science (see figure 1 below) and identifies the category of 'use-inspired basic research', which considers both the utility and the understanding function of science[14]. For Stokes (1997: 80), 'use-inspired basic research' would ensure the worth of science for the majority and reconcile the interest of scientists and their overseers or funders in a way pure basic research cannot.

Figure 1. Quadrant Model of Scientific Research

Research is inspired by:		*Considerations of use?*	
		No	Yes
Quest for fundamental understanding?	Yes	**Pure basic research** Example: physicist Niels Bohr's research on the atomic structure and quantum theory	**Use-inspired basic research** Example: biologist Louis Pasteur's discoveries of the principles of vaccination, microbial fermentation and pasteurization
	No		**Pure applied research** Example: inventor Thomas Edison's developments of the phonograph, the motion picture camera and the long-lasting, practical electric light bulb

According to Calvert (2002), Stokes' promotion of 'use-inspired basic research'

[14] To describe 'use-inspired basic research' Stokes introduced the term 'Pasteur's quadrant', in acknowledgement of Louis Pasteur's impressive translation of knowledge gained from chemical and microbiological research into vaccination technology.

has been highly influential among science policy researchers. Also, in the STS community, a wider interest in the objectives and outcomes of scientific research has motivated STS scholars to actively participate in science, technology, innovation and policy. For example, around the millennium, STS scholars began to identify such an interest and elaborate on the concept of 'Mode 2' knowledge production, which is said to be problem-focused, sensitive to real world applications and to involve multidisciplinary teams (Gibbons et al., 1994: 3, Nowotny et al., 2003: 179). In contrast, Mode 1 science refers to academic, investigator-initiated and discipline-based knowledge production, constructed as a rationale for scientific autonomy. Therefore, the concept of Mode 2 science, which has emerged from a changing scientific culture, has also become an aspiration derived from the STS community for a new form of socially robust and collaboratively assured knowledge production. However, a lack of empirical evidence supporting the proposal of Mode 2 science and the gap between policy and implementation as to the new governance of knowledge production have been debated and critiqued in SPS literature and higher education studies (e.g. Soudien and Gilmour, 1999, Kraak, 2000, Nowotny et al., 2003).

Meanwhile, the concept of 'post-academic' science (Ziman, 2000) and the 'Triple Helix' of university-industry-government relations (Etzkowitz and Leydesdorff, 2000) echo the importance of knowledge usage beyond disciplinary and institutional boundaries. Nevertheless, it has been argued that Ziman's meta-framework of science still presumes the naturalist realism of knowledge production and resembles the characteristics of Mertonian science: communalism, universalism, disinterestedness, and organized scepticism, a normative imperative for conventional academic science (e.g. Hooker, 2003: 76). Furthermore, scholars have reminded us that the 'Triple Helix' research model does not take into account past and existing transverse and entrepreneurial actions within academic research (e.g. Shinn, 2002: 611, Lawton Smith and Ho, 2006: 1554). Despite these critiques and reflections, STS scholars have generally encouraged the expansion, even the breaking of the triple-helix research network, or the so-called 'co-production' (e.g. Jasanoff, 2004) of knowledge, in which scientific ideas and beliefs, as well as associated technological artefacts, evolve with the representations, identities, discourses and institutions that give meaning and effect to scientific practices. In this active, pragmatic and participatory science-policy culture, the objectives and outcomes of particle and high-energy physics research, which remains a Mode 1 or academic science, require scrutiny. Interactions between the particle physics community and the science policy community are therefore worthy of investigation.

2.3 Evaluating Basic Physics Research

National science budgets, particularly in advanced countries, are influenced by fluctuations in economic and financial conditions (Martin and Irvine, 1983: 61, Stokes, 1997: 95); funding for science is, therefore, a pragmatic consideration. The SPS community has not only been re-evaluating the worth of pure enquiry but has proposed various approaches to the evaluation of curiosity-driven physics research (e.g. Martin and Irvine, 1981, 1983, 1984a, 1984b, Martin et al., 1987, 1996, Irvine and Martin, 1984a, 1985, Irvine et al., 1987, Hicks, 1992, National Research Council, 2001, Kanninen and Lemola, 2006, Wakeham, 2008, Science-Metrix, 2014, Hallonsten, 2016). Among these studies, I particularly want to discuss Martin's and Irvine's research published in 1983 (Martin and Irvine, 1983). Martin and Irvine have carried out the most systematic research on evaluating the outcome and performance of basic physics research, including the large-scale particle and high-energy physics research conducted at CERN. Being part of the economics tradition of their home institution – the Science Policy Research Unit (SPRU) at the University of Sussex – Martin and Irvine (1983) have developed a systematic bibliometric method – 'converging partial indicators' (CPI) – for the evaluation of scientific knowledge. Martin and Irvine argue that the assessment tools proposed in previous SPS research have provided fractional indicators that are only 'partly' determined by the magnitude of particular contributions to scientific knowledge. In other words, scientific indicators, including publications, citations and peer-evaluations, are also affected by 'other factors', such as various social and political pressures (Ibid.: 61). Moreover, as these other factors vary between scientists, groups of scientists and even periods of time, partial indicators, as understood by Martin and Irvine, cannot directly inform the science policy community about the performance of science, or provide accurate comparisons of performances by different scientific disciplines. Consequently, Martin and Irvine argue that it is not possible to anticipate where funding should be allocated within science and technology.

To address the limits of scientific indicators, the statistical method CPI, which aggregates scientific indicators and studies their implications at the research-group-level, has been used to identify the influence of other factors on scientific production as random or systematic effects. Martin and Irvine have claimed that once these effects – such as the publication practices of a research institution, area or country – have been removed, a research group's contributions to scientific knowledge can be predicted and compared with corresponding research groups. As a result, Martin and Irvine claim not only to have established a measurable definition of scientific progress but also to have developed a strategy to cope with the internal complexity of a measurement or indicator. In other words, the value and importance of curiosity-driven particle and high-energy physics research, once unpredictable or unmeasurable to the science policy community, can now be assessed, perhaps even predicted. These early works on research evaluation have inspired the development of a wider assessment framework that includes foresight, bibliometrics and citation analysis, as well as journal and university rankings, which interact with assessment practices in the science-policy community (e.g. Irvine and Martin, 1984b, Ramsden, 1994, Cave, 1997, Leydesdorff, 1998, 2001, Moed, 2005). Meanwhile, these actions or practices of 'measuring scientific values' have influenced how we define what the values of scientific research are.

Nevertheless, the use of CPI has encountered criticism or counter opinions from the fields of social and historical studies of science and the SPS community (e.g. Collins, 1985b, Krige and Pestre, 1985, Martin and Irvine, 1985, Hicks, 1992, Pavitt, 1997). In general, Martin and Irvine are criticised for overly defining the value or worth of scientific research according to internal epistemic achievement. For instance, Collins (1985b: 554) has stated that the assessment tool developed by Martin and Irvine only mirrors the context-dependent, internal reward system (peer review) of science. Similarly, historians of science John Krige and Dominique

Pestre (1985: 529), experts in the early history of CERN, have argued that Martin and Irvine have their own bias in the evaluation of science, prioritising the importance of scientific knowledge production over 'non-scientific' outputs. Although these critiques do not propose alternatives to existing assessment tools, they demonstrate concern within the humanities and social sciences about the broader value and importance of scientific research: also a force attempting to define the values of science. Moreover, SPS scholar Diana Hicks, a former student and colleague of Martin and Irvine, established that the research environments of sub-areas within elementary physics have different priorities, such as instrumentation development or increasing interdisciplinarity, and thus should not be governed by the same standard, or be evaluated in the same category (Hicks, 1992: 180). To avoid the misapplication of indicators to specific scientific performances, Hicks suggested evaluating research by combining bibliographies with qualitative interviews (Ibid.).

Hence, subsequent attempts to evaluate basic physics research have endeavoured to reach a broader understanding of the value and importance of physics through various approaches (e.g. Martin et al., 1996, National Research Council, 2001, Kanninen and Lemola, 2006, Wakeham, 2008, Science-Metrix, 2014, Hallonsten, 2016). A 1996 UK report on the relationship between basic research and its economic performance (Martin et al., 1996), conducted by the team at SPRU including Martin and Hicks, not only evaluated the economic influences of basic physics research but also took the 'non-information forms of output or benefit' of research, such as new interactions and networks, tacit problem-solving skills and knowledge translation or transfer, into consideration. A

2006 review of international research evaluation activities published in Finland (Kanninen and Lemola, 2006), advised that 'ex-post' (after the fact) assessment of the impact and societal and cultural influences of basic research, including elementary physics research, proved more effective than the foresight model inspired by CPI. Furthermore, with the decrease in funding for big physics research in the U.S., the research policy and business administration scholar Olof Hallonsten, an expert in the history and dynamics of big physics infrastructures, has suggested the science policy community differentiate between scientific facilities and their users, and evaluate the function and productivity of big physics infrastructures rather than their research performance (Hallonsten, 2016).

The various expectations of elementary physics research and big physics facilities held by the science policy community indicate the influence of multiple 'policy cultures', which, as observed by STS and SPS scholars, 'compete with each other for resources and influence, and seek to steer science and technology in particular directions' (Elzinga and Jamison, 1995: 575). Nevertheless, from the literature reviewed above[15], I have noted that research evaluation practices have shifted further and further away from the original concerns about the objectives of basic research and its correlation with research outcomes (e.g. Irvine and Martin, 1984b, Martin, 1995, Gibbons et al., 1994, Stokes, 1997, Nowotny et al., 2003). Moreover, I argue that the assessment tools proposed thus far, whether

[15] To clarify, my literature review in this section focuses on the methods, models and approaches proposed for evaluating the worth of particle or basic physics research. Since I am interested in how the value or worth of particle physics research is established or constructed, I do not attempt to emphasise 'what' value or worth has been identified.

quantitative or qualitative and including evaluation of economic performance and consideration of societal and cultural impact, fail to provide a method for investigating the aspirations of the scientific community. In other words, research evaluation activities remain at the behavioural level, studying the evidence supplied by scientists and not examining how and why behaviours and facts provided in response to external scrutiny are constructed. I argue that research evaluation, therefore, overlooks dynamic interactions between policy cultures – bureaucratic, academic, economic, civic, etc. – that represent the various interests of different institutional bases and traditions (Elzinga and Jamison, 1995: 575). For example, the Leiden Manifesto for Research Metrics (Hicks et al., 2015) mentions the fact that the evaluation culture of the science policy community may incite a 'score boasting' culture within the scientific community. Hence, in addition to reforming the practice and interpretation of bibliometrics, I argue that we need qualitative information to evaluate the intentions and interests—indeed the occupational culture—of the basic physics community in response to contemporary science policy agendas.

To clarify, I am aware of the scepticism felt by many academics towards research evaluation and assessment policy: a phenomenon framed by sociologist John Brewer as 'the impact of impact'[16]. For instance, scholars are concerned about the reductionist audit culture of governance interwoven with performance metrics (Strathern, 1997: 305, Power, 2004: 765), restrictions to academic autonomy, the possibility of 'boundary-work' in accounting for impact, the constraints imposed by

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[16] See more in: BREWER, J. D. 2011. The impact of impact. *Research Evaluation,* 20, 255–256.

the framing of impact (Smith et al., 2011: 1369) and the substantial cost of the evaluation framework (Martin, 2011: 247). However, as these studies also accept, I argue we have to face the changing social contract of science squarely and avoid denying the necessity of evaluating the worth of research on stakeholders' behalf. That is to say, my thesis is also a reflection on the need to improve evaluation practices, particularly by taking a holistic approach that considers not only quantitative variables but also qualitative, contextual processes to evaluate the extra-academic impact of publicly-funded research. Claims have recently been made that a more qualitative approach to research evaluation is the future of post-NPM governance (e.g. Donovan, 2007: 592–594).

2.4 Studying the Mundane Interactions of the Basic Physics Community

To understand and evaluate the objectives of the basic physics community, I suggest we learn from the epistemology and methodology of the STS community. There is abundant STS literature investigating the cultures and social worlds of elementary physics research, especially in relation to knowledge production (e.g. Collins, 1985a, 2001, 2004, Pickering, 1984, Pinch, 1985, Shapin and Shaffer, 1985, Traweek, 1988, Galison, 1997, Knorr-Cetina, 1999, Doing, 2009, Reyes-Galindo, 2014). Through textual and embodied information, these studies focus on the beliefs, interests and practices of physicists in the construction of knowledge that may once have been internally disputed, but are now widely taken as standard practices, objective facts or credible answers to the human dilemma. Anthropological and laboratory studies of the physics community have approached physicists' collective practices and multiple versions of knowledge production through in-depth interviews and participant observation.

For example, Collins (1985a: 79–111) has posited a loop of dependence, which he terms 'experimenter's regress', in which physicists' appraisal of evidence must rely on theory-laden expectations, while the evidence produced by physicists is the only means of judging the value of competing theories. I argue that the wider value or worth of particle physics as evidenced and appraised by physicists and other community members, and communicated by them beyond the research community, may also be interwoven with their expectations and presumptions. However, a difference exists between experimenter's regress and accounting for scientific values, since any cross-boundary communication of value is interrelated with the judgment and agreement of external actors. Therefore, identification of a loop of dependence regarding the construction of scientific values requires analysis of the interactional cultures between science, policy and society, such as the 'impact' culture, the 'indicator' culture and the 'public engagement' culture. The anthropologist of particle physics, Sharon Traweek (1988: 6), has noted that when granting researchers access to the high-energy-physics (HEP) experimental facilities to acquire data and resources, it is necessary to balance the interests of resident research groups with those of visiting groups. I argue that the micro-politics—the balance of interests of different subgroups in the HEP community—is likely to interplay with the construction of the value or worth of particle physics research, which is also a way to gain access to resources. Furthermore, the sociologist Knorr-Cetina (1999: 63–70) has detailed a culturally-rich internal environment at CERN, which influences both the epistemic status of individual particle physicists and the forms of reason they provide. This means justifications provided by particle physicists and the status of these claims is interdependent with the culture, shared opinions and attitudes of the research community. I argue this social process also applies to particle physicists' justifications for the value or worth of their research.

While these STS works focus on interactions between physicists, studies in the history of science[17] have examined the physics community in interaction with politics, cultures and social-economic conditions. Examples include research into the interconnections between Weimar culture and quantum theory, and between American national security and quantum electronics (Forman, 1971, 1987). Historians have also investigated the public demonstration ability of modern physics experiments, which triumphed over the epistemic authority of natural philosophy in 17th century Europe (Shapin and Shaffer, 1985), and have analysed the post-war context to understand the 'production' of American physicists and the visual dispersion techniques of theoretical physics (Kaiser, 2002, 2005). For instance, Shapin and Shaffer (1985: 24) note: *'An experience, even of a rigidly controlled experimental performance, that one man alone witnessed was not adequate to make a matter of fact. If that experience could be extended to many, and in principle to all men, then the result could be constituted as a matter of fact.'* Therefore, for 'a matter of fact' to become 'a matter of fact' in society, both an epistemological awareness from individuals and a sociological acknowledgement from a social group are required. I find these historical studies

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[17] I am a sociologist by training. Therefore, for this thesis, I have reviewed more sociological studies of physics than historical studies.

insightful for understanding the value and importance of basic physics research, which is constructed beyond the research community, and in collaboration or tension with other authorities and external conditions.

However, it is the anthropological and laboratory studies of the physics community that resonate most with my original motivations for this thesis (read more in section 1.1: p. 27); namely, to observe and participate in the interactive constructions of the value and importance of particle physics research. Even though I estimate that the topic of value and importance is likely to require active probing of the interviewer, and thus a totally spontaneous method of participant-observation is not possible in my thesis, a semi-structured and open-ended interview approach can still preserve, to a certain extent, the anthropological element of qualitative research methods (more discussion in chapter 3: from p. 89 on). I believe this is both an executable and efficient pathway to understanding the intentions of members of the particle physics community in response to policy and societal expectations, since interactive and spontaneous reactions are still likely to be observed in these interviews. Furthermore, it is worth noting that the interviewer, aside from encouraging the respondents to elaborate on the research topic, must avoid defining the value and importance of particle physics in advance. The research design I use, which takes possible differences between interlocutors into consideration, will be discussed in the methodology (refer to sub-section 3.3.2: p. 97). Although anthropological and laboratory studies in STS aim to explain the social and cultural processes of internal knowledge production, I believe the same approach can be applied to study interactions between the scientific community and policy expectations relating to the wider value of research: in other words, both the ‘trustworthiness’ and the ‘worthwhileness’ of science require discursive and practical justification within and beyond the laboratory.

Interactions between scientific communities and wider social, political and economic contexts are of major interest to the STS community (e.g. Gieryn, 1983, 1999, Law, 1984, Star and Griesemer, 1989, Latour, 1993, Mulkay, 1993, Hilgartner, 2000, Yearley, 2005a, Slayton, 2013). Among these studies, I find the sociologist of science Thomas Gieryn’s concept of ‘boundary-work’ (Gieryn, 1983, 1999) particularly inspirational. The term ‘boundary-work’ refers to the constant relational and dynamic practices carried out by a scientific community to construct and maintain the value and status of science while its professional interest is in confrontation with other authorities. For instance, Gieryn (1983: 784) has argued that the physicist John Tyndall, in order to promote science in Victorian Britain, represented scientific research in his lectures and publications as pure, sacred and highly cultural as religion. Moreover, Gieryn also describes the concept of ‘boundary-work’ within ‘the cartography of cultural boundaries’ (1999), emphasising the plural constructions of scientific authority, and its status, which is not only epistemic but also social and cultural. I find that Gieryn’s perspective on the multiple representational practices of the scientific community opens up the possibility of understanding the various values claimed for basic physics research in response to different contexts, including the policy one.

The epistemology of the ‘boundary-work’ concept echoes an important epistemological shift within the STS community: the ‘practice-turn’ (e.g. Pickering, 1993, 1995, Schatzki et al., 2001, Soler et al., 2014), which arose as a challenge to a reliance on theory and the reification of language within the Sociology of

Scientific Knowledge (SSK). While SSK aims to provide sociological explanations of the cause of scientific knowledge by investigating a wide range of formal and informal scientific texts, the practice approach in STS not only critically challenges the 'face value' of scientific texts but also the speech, writings and practices of scientists in historical contingencies and on-site practices. In other words, the epistemology of the practice-turn focuses on the contextual-dependent, representational 'activities' of science rather than the representations themselves: ideas and materials cannot take a place in the social world without the collective practices between subjects, objects, humans, artefacts and Nature. Thus, we cannot understand and claim a fact without a systematic understanding of its multiple facets and how they have been practised (Schatzki et al., 2001: 40). For instance, through a historical study of the construction of the bubble chamber—an apparatus invented in the mid-1990s to detect the movement of electrically charged particles—Pickering (1993: 568) argues that both material contours and accounts of its character are emergently produced in a real-time dialectic of resistance and accommodation, implying that materiality and practices are interwoven[18]. Therefore, any assessment of the value or worth of particle physics research has to consider its practices.

To clarify, while resonating with the practice turn in STS, this research can still be based on words and languages. While gaining insights from investigating scientific practices, it will also improve our understanding of and approach to studying words

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[18] Since this thesis focuses on collective practices relating to the value and importance of particle physics research, my discussion of the practice-turn in STS does not include the debates between humanists and post-humanists, or modernists and postmodernists, concerning the formation of scientific knowledge.

and languages. That is, we can study the use of words and arguments as discursive practices rather than static text. Following the epistemology of the practice turn in STS, which has also been labelled ‘constructivism’ by STS scholars (Schatzki et al., 2001: 40), we can understand the value and importance of particle physics research as ‘value claims’ and ‘value practices’ that require analysis within the context in which these claims are used, or with which these practices interact. In other words, constructivism differs from constructionism in that it does not seek to determine a single causal relationship, and acknowledges both the multiple possibilities of reality and the inconsistencies between different versions of reality (e.g. Woolgar, 1983, Lynch, 1992).

Furthermore, I suggest we can draw on the ‘quiddity’ or ‘haecceities’ metaphor utilised by the founder of ethnomethodology, Harold Garfinkel (1988: 103, 2002: 67), to illustrate what we can learn from the study of value claims and practices. Ethnomethodology (Garfinkel, 1967, 1988, 2002) provides an approach to studying the way people make factual descriptions that they and others can perceive as adequate, appropriate and justifiable. The term ‘haecceity’, originating from Latin, means the ‘what-is’, the ‘this-ness’, or the ‘essence’ of a thing. Garfinkel used this word to emphasise the importance of studying the contingencies in which people account for and interactively negotiate ideas and things in everyday situations. As I aim to think beyond face values, and explain why things and ideas are described as they are, I consider my enquiry into the value and importance of particle and high-energy physics research to be a study of ‘haecceity’. I believe that this analytic angle facilitates an understanding of the intentions of actors, as well as their culturally-appropriate discursive practices in the construction of the value and importance of particle physics research. As a result, in the next section, I will introduce and explain a methodological framework that enables the empirical study of relational discursive practices at the nexus of science, policy and society.

2.5 Ethnomethodologically-inspired Discourse Analysis (EIDA)

The constructivist approach in STS that studies knowledge production and factual descriptions has inspired me to attend to the 'usages' of language, evidence and argument to justify the value and importance of particle and high-energy physics research beyond the research community. Among those STS scholars concerned with the construction and reconstruction of knowledge and facts is the sociologist of science Michael Mulkay, who has systematically analysed the discursive practices of scientists. In fact, Gieryn's research on the boundary-work of scientific authority has benefited from Mulkay's analytic approach to understanding the cultures of science, which Mulkay considers 'vocabularies' for ideological descriptions of science (Mulkay, 1976, 1979, 1980, as cited by Gieryn, 1983). However, Gieryn has stated that Mulkay's work *'remains to demonstrate empirically how scientists in public settings move flexibly among repertoires of self-description'* (Ibid: 783). Mulkay's later work, in collaboration with the sociologist Nigel Gilbert (1984), is an advancement and a systematic analysis of scientific discourse.

Furthermore, Gilbert and Mulkay's work (Ibid.) shares a commonality with ethnomethodology: both frameworks systematically study the interactive details of what scientists write, do and say, regardless of whether these discourses and practices are competing and contradictory (Yearley, 2005b: 83–98). Neither ethnomethodology nor the constructivist discourse analysis pioneered by Mulkay intends to provide constructionist explanations; rather, these approaches aim to systematically explain how the mutually competing or contradictory claims are used by actors interchangeably, and in what contexts these discursive practices appear. As reviewed in sections 2.2 (from p. 56 on) and 2.3 (from p. 63 on), the values claimed for particle and high-energy physics research and assessments of the value of basic physics research all have contexts for their existence within different policy interactions and socio-economic conditions. Therefore, for this thesis, I regard the methodological framework provided by constructivist discourse analysis and ethnomethodologist epistemology as more relevant than constructionist approaches[19].

To clarify, the methodological framework I apply here lies between ethnomethodologically-inspired constructivist discourse analysis and the constructionist approach, rather than relying entirely on either. I not only seek to explain how the discursive practices of the particle physics community are presented, but attempt to understand why these actors utilise discursive practices in the manner they do. My reasoning includes the fact that I disagree with Mulkay and Gilbert's scepticism towards the association between actors' speeches and the reality. In other words, Gilbert and Mulkay (1984: 64) regard actors'

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[19] Ethnomethodology and constructivism are both critiques of sociological constructionist approaches that generalise from evidence collected and propose grand theories to systematically explain the social world. In this thesis, I do not intend to generalise from the systematic patterns I study. I will explain the implications and limits of this approach in chapter 3 (from p. 89 on).

articulations of beliefs or interests as mere 'talk': a specific passage of speech or a particular unit of discourse that is continuously formulated and reformulated according to interactional needs. Therefore, they believe these fundamental units of analysis cannot be analysed by macro-sociology, which tends to generalise findings from local contexts to grand theories. I agree with Mulkay and Gilbert regarding the importance of the connection between researchers' argument and the context they study. However, I still consider the identification of actors' systematic discursive techniques, particular rhetorical devices and recurrent repertoires as relatively stable social realities that can be a pathway to understanding the contextual ideas and the interactive interests of the actors studied. The ways in which people organise their actions and practices (the 'how' question), regardless of whether they are conscious or unconscious, require psychological and social triggers in need of explanation (the 'why' question). Despite the fact that constructivist discourse analysis does not analyse objective facts through discourse, it is applied in the field of social psychology to understand attitudes, categories, social representations and rules (Potter, 2007).

Moreover, even in Mulkay's later study of the embryo research debate (Mulkay, 1993), he noted that actors derive their discourses from existing cultural resources shared with others, such as the collective understanding of hope and fear. It has been proposed that the argument Mulkay (Ibid.) uses in this instance goes beyond 'discourse as the fundamental unit of analysis' (Yearley, 2005b: chp. 6, p. 11), and thus suggests that discourse is interconnected with the collective interests, beliefs and so on of a group of social beings. Taking this middle-ground approach, I am aware that my answer to the 'why' question—why the value and importance of particle physics are articulated in the manner they are—cannot explain beyond the research community and the similar contexts that I have investigated. That is, the particle and high-energy physics community, and in well-founded situations, other curiosity-driven research communities.

Furthermore, although the ethnomethodological study of 'haecceities' facilitates investigation of the 'essence' of science as discoursed and practised, I do not plan to employ the ethnomethodology-influenced technique of 'conversation analysis'. My reasoning here is practical: conversation analysis has a set principle that focuses on turn-taking, repair, action formation and ascription, as well as action sequencing (Potter, 1996: 42–67). My interest in the intentions behind constructing the value and importance of particle physics research requires long and in-depth discussions with members of the research community. This will result in a vast amount of data that I have no means to manage in accordance with the transcribing criteria of conversation analysis. As a result, I have named the methodological framework of this thesis 'ethnomethodologically-inspired discourse analysis' (EIDA) to represent the combining of methodological insights from both approaches and emphasise the importance of studying the 'haecceities' or essence constructed. In the passages below I discuss work that fits with the characteristics of EIDA and is therefore relevant for my empirical analysis.

2.5.1 Empiricist and Contingent Repertoires

Gilbert and Mulkay's (1984) study of the various presentation styles used by biochemists to explain what they think is the correct and incorrect knowledge in their field, found that the discourse of scientists not only includes objective evidence but also draws on social and political factors associated with the production of scientific knowledge, such as the biographical and personal features of scientists. Gilbert and Mulkay have therefore differentiated two major styles of discourse, the *'empiricist repertoire'* and the *'contingent repertoire'* (Ibid: 40), which are interchangeably employed by biochemists according to different discursive contexts in the same scientific dispute[20]. In other words, scientists' factual descriptions of, or explanations for scientific knowledge are fallible and not always non-objective. Gilbert and Mulkay (1982: 383) discovered a consistent discursive pattern practised by both camps of biochemists they interacted with: both tended to use an empiricist repertoire to account for their own scientific belief but use a contingent repertoire to describe the beliefs of their rivals. This finding implies that we cannot rely on the claims of a single camp to determine whether a fact or belief is correct or not, since there may be a rival camp using the opposite discursive technique to refute the fact or belief. Consequently, Mulkay and Gilbert (1984: 69–81) suggest that we consider scientists' account of their belief—the 'haecceity' or essence of a scientific camp—as asymmetrical accounting in favour of their own stance. Moreover, the transition and translation between empiricist and contingent repertoires requires analysis as these embody the systematically asymmetrical attitude of scientists.

2.5.2 Reconciling Contradictions in Repertoires

A transition between repertoires, however, is likely to cause inconsistency in the overall appearance of science, and therefore needs rhetorical management to avoid apparent contradictions between interpretative variations. Gilbert and

[20] The empirical ground of Mulkay and Gilbert's work is based on their informal interactions with biochemists.

Mulkay (1984: 90-111, 172–187) have investigated the discursive techniques and rhetorical devices that are used in the nexus between inconsistent repertoires and serve to reduce these contradictions (rhetorical traps). Two of the devices identified by Gilbert and Mulkay are particularly relevant for studying discussions of the value, importance or 'haecceity' of particle physics research.

The first is the recurrent and systematic appearance of the 'truth will out device' (TWOD) (Gilbert and Mulkay, 1984: 90), found in the context of accounting for error. When biochemists use interchangeably contingent and empiricist repertoires to explain the quality of competing theories, the TWOD, which tends to appear at the end of contradictory accounts, is a useful rhetoric to resolve interpretative difficulties between the repertoires. For example, the function of the TWOD is shown in the following sentences: *'I think ultimately that science is so structured that none of those things are important and that what is important is scientific facts themselves'* (Gilbert and Mulkay, 1984: 93), and *'But I have great faith, in fact, that eventually we will know what's going on and that's all the question really is.'* (Ibid: 100). As shown, the actual contents of the TWOD vary from interview to interview but all possess the same characteristic: an interpretation of temporality embodied by the words 'ultimately' and 'eventually'. When scientists have insufficient evidence to relate and have resorted to a contingent repertoire, interpreting temporality restores, to a certain extent, the primary status of the empiricist repertoire in the discursive context. That is, with the TWOD, *'experimental evidence is depicted as becoming increasingly clear and conclusive over time'* (Gilbert and Mulkay, 1984: 109). I argue that accounting for both competing theories within biochemical research and the value of undetermined results within particle physics research are situations in which the empiricist repertoire is not enough for sense-making. Therefore, in the empirical work of this thesis, I will need to be sensitive to the appearance of the TWOD and vacillation between repertoires, which is likely to be found whenever logical fallacies occur within discourse.

The second device identified by Mulkay and Gilbert (1982, 1984: 172–187) that has relevance here is one that reconciles discursive contradictions non-verbally. They found that scientists employed humour as a device, embodied by laughter or an ironic tone of voice, to rationalise the juxtaposition of inconsistent repertoires in asymmetrical accounts. The characteristics of the joking element in biochemists' discourse differ from those of the TWOD in a number of ways. For one, laughter or an ironic tone is an indirect and informal device, which manages discursive inconsistency without any lexical or structural change of discourse. Also, unlike the rhetorical insistence of TWOD that skips over contradictions, the act of joking implicitly suggests to the audience a scientist's acknowledgement of their discursive inconsistencies and asymmetrical attitudes. However, as Gilbert and Mulkay (1984: 175) noted: *'humorous incongruity is likely to be disregarded and "not taken seriously"'*, that is, the discursive inconsistency that is interwoven with a scientist's laughter or ironic tone are difficult to notice during interactions. For instance, Gilbert and Mulkay (1984: 176) discovered what they termed a 'proto-joke' pinned on the notice board of the laboratory they visited, in which the differences between scientists' representations and their actual thoughts in academic writings were presented boldly and ironically. Consequently, humour resembles the TWOD in that it enables scientists to move between repertoires and keep the discourse coherent and unproblematic; it does not stand apart from the production of serious discourse but is one aspect of the diverse interpretations of the world that deserves attention here.

2.5.3 The Status of Science

To put it in other words, Gilbert and Mulkay encourage the study of more general patterns of sense-making in science which is the objective of this thesis. Aside from biochemists' discourses on scientific knowledge, Mulkay has also studied the way Nobel Laureates respond to compliments in formal and informal interactions (Mulkay, 1984), and the arguments for or against embryo research in UK parliamentary debates (Mulkay, 1993). In these studies, Mulkay found that Nobel Prize winners achieved socially-expected levels of modesty by redistributing the praise they received to colleagues and the entire scientific community (Mulkay, 1984: 532), and speakers supporting embryo research in parliamentary debates employed the rhetoric of hope, while those opposed used the rhetoric of fear (Mulkay, 1993: 733). I argue that these general patterns of sense-making by the scientific community indicate an awareness of the importance of managing the status of scientific claims, and how the status constructed can determine the amount of respect and support a subject receives. As a result, the status of science is interrelated with the claimed and practised value and importance of science; the subject of this thesis.

As I understand his work, Mulkay does not propose a precise framework for studying the status of science constructed in discourse. However, my work has been informed by the insight of another constructivist discourse analyst, Greg Myers, who has studied the status of scientific knowledge formed in the process of academic writings (Myers, 1985, 1990). Myers analysed the interconnection between the style of a text and the status that text attained. By studying interactions between biologists and journal editors in regard to article acceptance and publication, Myers discovered a hierarchy of claims, in which higher level claims are profound but precarious statements, while lower level claims are conservative statements that run the risk of being dismissed as trivial (Ibid.: 607). Furthermore, a decision about the level of a claim is negotiated between authorship and readership. This negotiation or interaction implies that the 'appropriateness' of a claim in a disciplined text determines whether the reality claimed is accepted or not (Myers, 1985: 605). For example, Myers (Ibid.) studied two biologists whose research papers refuted mainstream theories, and discovered that a discursive emphasis on one's own epistemic importance was not deemed a valid justification: a discourse that managed the importance of the theory being refuted proved to be more trusted by journal editors. In other words, to make the communication of scientific knowledge or belief credible, scientists have to find their niche in the hierarchy of claims and present their evidence or justification accordingly. In addition, Myers also found that at times biologists would make the 'strategic mistake' (Ibid: 615) of overstating the value and importance of a claim, to adventure into increasing the status of the claim.

In the empirical work of this thesis, I will therefore pay close attention to the placement of claims and the tones that strategically express the value and importance of particle physics research.

2.6 Practical Implications of a 'Discursive-practice-centred' Approach

I argue that the practice-centred approach to studying the articulated worth of elementary and particle physics research will benefit the research agenda of the STS community in the 21st century, which aims to participate in the process of knowledge production and technological innovation (e.g. Gibbons et al., 1994, Etzkowitz and Leydesdorff, 2000, Ziman, 2000, Nowotny et al., 2003, Jasanoff, 2004). That is, STS scholars interested in the interconnection of science, policy and society, expect to be able to integrate social, economic, political and environmental concerns into present and future science and technology. Hence, I argue, a necessary step towards achieving such integration is to understand how the scientific community thinks about these wider concerns and practices in its relationships with society.

Moreover, most research within SPS has disregarded the attitudes and opinions of members of the particle and high-energy physics community in response to external expectations and policy agendas. I believe this type of empirical phenomenon is important as it enables investigation into the way particle physicists adjust their ideas, opinions and practices with a changing science-policy culture. In other words, my interest in studying how and why the worth of particle physics research is constructed in the way it is, has the capacity to fill a gap in SPS literature, through analysis of the discursive and behavioural patterns of particle physicists in response to external actors, expectations and cultures. In this way, we can better understand the alignment of the particle physics community's objectives with current science policy, and this community's self-justification of the value and importance of particle physics research.

In the following chapter on methodology, which includes research questions, strategy and design, I explain the choices and considerations I have made to collect and generate the empirical evidence that resonates with my discursive-practice-centred research interest. In addition, I demonstrate the way I have transcribed and stored data, thereby ensuring the information is approachable in the manner required for EIDA. Furthermore, I illustrate how I have used qualitative analysis software to prepare for the use of EIDA, and discuss the implications, limitations, possible improvements and ethical issues associated with EIDA.

Chapter 3 Methodology

Studying the Constructions of 'Worth' for Particle Physics

3.1 Research Questions

The publicity generated by the discovery of the Higgs boson has provoked many discussions on the value and importance of particle and high-energy physics research. In between the expensive but esoteric knowledge acquired from the deep underground accelerator and the pragmatic science-policy agenda that emphasises efficiency, impact and social responsibility, the worth of research on the Higgs boson and beyond demands justification. Although the SPS community is concerned about the objectives of scientific research, the research evaluation policies and assessment tools they recommend are focused more on the outcomes of research than on its goals. The epistemology of STS literature, however, provides a convincing approach towards understanding the actors' and their community's context-dependent and culturally entwined discourses and practices. Therefore, to go beyond the outcome evaluation of research and back to a significant discussion about the objectives of research, I aim to study how and why the value and importance of particle and high-energy physics (HEP) is constructed and reconstructed by members of the particle physics community.

In this thesis, I have converted my topic of interest and research objective into three research questions, as follows:

1. *How do members of the particle physics community explain why their research is valuable?*

2. *Why does the particle physics community represent its value and importance to society in the way it does?*

3. *Has the policy agenda changed how the particle physics community manages itself?*

As shown by these research questions, this thesis concentrates on the discourses and practices of members of the particle physics community. In studying the value or worth constructed for particle and high-energy physics research, I want to explore a) whether or not these members are faced with any external factors that affect how they talk about the value and importance of particle physics, b) what factors the research community refers to when it is necessary to demonstrate the significance of particle physics in public, and c) the practices undertaken by members of the particle physics community in reaction to the contemporary science-policy agenda on the impact and social responsibility of research. Therefore, EIDA (Ethnomethodologically-inspired Discourse Analysis) is a useful approach to understanding these interactions between discourse and context.

EIDA is informed by constructivist discourse analysis in the STS literature. It is different from conversation analysis by paying less attention to the nature of transitional interactions between speakers (Potter, 1996: 42–67, Wooffitt, 2005: 5–13), and can incorporate not only interview data but also documents. Hence, EIDA is a better method in this thesis for achieving my research aim of identifying the general patterns of value claims made by members of the particle physics community. Nevertheless, to identify the logical fallacies and rhetorical devices used in asymmetrical accounts, EIDA does direct a certain degree of attention to interactions within the discourse. EIDA also differs from critical discourse analysis, which refers to abstract sociological concepts such as social class, social inequalities and power-relations to explain discursive interactions (Potter, 1996: 224–242, Wooffitt, 2005: 137–145). Inspired by constructivist epistemology, I believe the abstraction of critical discourse analysis overlooks the dynamics of locally-produced discursive context, and falls into the trap of providing a relativist account that uncritically accepts the researcher's construction of a fact (Angermuller, 2018: 4). The contextual abstraction and conceptualization of research objects requires scrutiny, which can be achieved by EIDA through a detailed analysis of the language-use, rhetoric and repertoire constructed according to interactive situations.

However, since the literature that informs EIDA, especially the 'rhetoric of hope and fear' studied by Mulkay (1993), has also been methodologically challenged (more discussions in section 2.5: p. 76), I cannot argue that EIDA is the best form of discourse analysis. Still, the strength of this approach is that it takes a middle-ground position with a focus on interactive, collective language practices, and connects sociolinguistics' study of rhetoric with critical discourse analysis' study of wider (not necessarily macro) social contexts. Moreover, the emphasis within ethnomethodology on the study of 'haecceities' (Garfinkel, 1988: 103, 2002: 67) also implies the importance of exploring the research objects' own sense-making. Therefore, the use of EIDA aims to acquire a contextually rich understanding of the worthwhileness (haecceities) of particle physics research, as it is articulated and practised. That is to say, I regard actors' accounts and sense-making as my object of study rather than a source of explanation. My research is sensitive to the formation of value *in situ* and I will avoid taking actors' accounts at face-value or being influenced by existing approaches to studying the value of science in SPS literature (more discussions in section 2.3: p. 63).

3.2 Research Strategy

A qualitative research design is most suitable for the epistemological stance and objective of this thesis, which aims to participate in and investigate constructions of the value or worth of particle and high-energy physics research as well as the interactions taking place in these constructions. To study how members of the particle physics community interact with external actors and expectations, I have designed an interview-based and document-supported methodology, in which I can, to a certain extent, participate and observe these members' cross-boundary interpretations of the value and importance of particle and high-energy physics research. To clarify once more, I consider in-depth interviewing a more feasible approach than ethnography for this thesis, as the interactive and spontaneous discursive construction of value requires prompting and probing. This empirical data will provide SPS with the microscopic and situated information required to understand the reasoning behind the discourses and practices employed by members of the particle physics community, an angle neglected by conventional research evaluations.

3.2.1 Limitations and Improvements

An actor-oriented qualitative study can rarely produce generalisable results since each interaction is interdependent with the situated context. Nevertheless, my study of individuals' opinions and discursive practices, informed by constructivist discourse analysis (more discussions in section 2.4: p. 69), is an appropriate strategy for investigating the recurrent discursive or behavioural patterns of the particle physics community. Hence, within the cases I study, I am able to explain a wider phenomenon beyond the individual-level. Meanwhile, I regard documentation to be also a space inscribed with discursive practices, in which the value and importance of particle physics is textually constructed and reconstructed for representation. My view echoes the practice-based approach to policy studies (Freeman et al., 2011, Freeman and Maybin, 2011, Behagel et al., 2017). For instance, it has been argued that policy documents are both *'traces of action, and triggers of action'* (Freeman and Maybin, 2011: 162), reflecting the layers of construction written policy texts undergo that also require analysis. Discursive-practice-centred epistemology enables me to investigate the context-dependent representational practices of documentation rather than merely its literal meaning. Therefore, the interview-based methodology of this thesis is supplemented by document analysis, which will enable access to the discursive practices of the wider particle physics community and go some way to addressing the generalising limitations of my interview sample. A combination of and comparison between different types of data will facilitate the triangulation of my findings and expand my arguments.

3.2.2 Social Epistemology

The research strategy of this thesis is inspired by sociologist Howard Becker's (1996, n. d.) writings on qualitative research. Becker (1996, n. d.) has suggested social researchers focus on actors' behaviour and the internal logic of their conduct. For example, Becker notes (n. d.: 6): *'qualitative methods insist that we should not invent the viewpoint of the actor, and should only attribute to actors ideas about the world they actually hold, if we want to understand their actions, reasons, and motives.'* I argue that EIDA, which incorporates Gilbert and Mulkay's (1984) insights into the contingent and empiricist repertoires, as well as the rhetorical traps between different repertoires, and Myers' (1985, 1990) insight into the status of the scientific discourse or text represented, enables me to approach the logic of the discursive practices of the particle physics community, and thus interpret the reasoning and motivations behind such practice. Consequently, in constructing my research design I must avoid imposing my own interpretations and preconceptions of the value and importance of particle physics research.

This social research stance is close to abductive reasoning or the concept of 'inference to the best explanation'. For instance, in a leading textbook on designing social research, the author (Blaikie, 2000: 115) explains that an abductive research strategy *'seeks to discover why people do what they do by uncovering the largely tacit, mutual knowledge, the symbolic meanings, motives and rules, which prove the orientations of their actions.'* The epistemology of abduction pays attention to actors' worlds as well as their world views and behavioural strategies. Inspired by the Analysis of Scientific Discourse in STS literature (e.g. Gilbert and

Mulkay, 1984, Myers, 1985), I pay particular attention to the language-use, discursive-practices and storytelling of the actors in order to understand their opinions, attitudes and cultures. My intention here is to understand the interconnections between the actions, reasons and motives of members of the particle physics community while negotiating the worth of particle and high-energy physics research.

Moreover, because I aim to study the constant constructions and reconstructions of the value and importance of particle physics research, rather than pin down what the value and importance of particle physics might actually be, my epistemological stance is similar to that of 'methodological relativism' (Collins and Yearley, 1992: 304–308). As described in Social Studies of Science literature, methodological relativism rejects any form of fundamentalism and its replacement in the understanding of the formation of scientific knowledge (Ibid: 308). I do not take the truthfulness or falsity of any value claimed in the interviews or documents I have reviewed as evidence, but rather examine how and why the truthfulness and falsity are explained in the way they are in these contexts. My research strategy for studying the discursive practices of members of the particle physics community resonates with the discourse analyst Jonathan Potter's interpretation of methodological relativism (1996: 25): *'Scientists' claims about what is true and false should not be taken as the starting point for analysis but should become a topic of analysis in their own right.'* I believe that interpretations of value, regardless of their veracity, require repeated examination by social and political science through context-sensitive analysis.

3.3 Research Design

3.3.1 Ethics

This thesis was ethically approved by the School of Social and Political Science Research Ethics Committee[21] prior to first-year progression board in July 2015. When accessing and analysing policy documents I have always complied with the terms and conditions of these documents, and stored them in a password-secured hard or virtual drive. When conducting interviews I have always informed my interviewees about the purpose, background and process of the interview, and obtained their written consent before or after the interview. Any confidentiality and anonymity requested was considered top priority, in order to protect their position in relation to scientific research and policy making. However, since my study focuses on a specific group who generally share the same social network, the possibility of my interviewees identifying each other had to be addressed. Therefore, if I heard an opinion/comment during the interview that might be too critical or sensitive, I noted this down but avoided circulating it, or double-checked with the interviewee. Lastly, I provided the opportunity for all interviewees to review a transcript of their interview if they so desired.

In the following sections I will explain my methods of data generation and collection, and the ethnomethodologically-inspired analytic approach designed for this thesis, which focuses on the importance of situated interactions in the formation of the value and importance of particle and high-energy physics research. Furthermore, when explaining my research design, I will discuss the

[21] The School's webpage: www.sps.ed.ac.uk/research/ethics

challenges, limitations and ethical concerns raised by my empirical approach, and give an account of how I managed these issues.

3.3.2 Interview Generation

Rationale

In order to generate data that captures the interactive constructions and negotiations regarding the value and importance of particle physics by members of the particle physics community, I transformed my research questions into semi-structured qualitative interview designs (Fielding and Thomas, 2001: 245–265). In the interview guides (see Appendix A: p. 247; and Appendix B: p. 249) designed for members of the particle physics community – particle physicists and knowledge transfer officers in particular – there are three sets of questions, with each set having a distinct aim:

1. *To prompt interviewees to describe their personal value and identity*
2. *To generate explanations of their frequently-used formal accounts justifying their community's value and importance to non-members*
3. *To encourage reflection on the degree of consistency between their accounts and practices.*

I guided each interviewee through these three stages to observe their reactions to a situation that bears similarity to the conjunction of the scientific community, society and the policy community. In addition, with these different sets of interview questions, I extended my research from the situated accounts of the value and importance of particle physics in the interviews to the value claims made for wider communications[22].

To clarify, the interview guides I designed for this research were not a rule book to be rigidly followed; rather, I regard these questions as icebreaking topics that enabled me to open up interactive discussions and participate in my interviewees' sense-making processes. I piloted the interview guides with young particle physicists and discussed the outcome with my supervisors to refine the questions. This process was a negotiation between the research questions of my thesis and the topics my interviewees had a tendency to elaborate on. To ensure that interactions were natural and spontaneous, I made slight changes to the order of questions and added follow-up enquiries as necessary. An entirely structured close-ended interview would narrow the discursive space available to my interviewees. However, an unstructured and open-ended interview would also be inappropriate, as the interviewees might digress too far from my thesis topic.

Although interviewing is not the only research method that can generate interactive and spontaneous dialogue—focus groups and ethnography, for instance, also have the potential to reveal actors' practices and discourses *in situ*—conducting one-to-one interviews enables in-depth discussions about the motivations, assumptions and expectations that are not always observable in group discussions or random conversations. As a result, I consider interviewing to be the best method for me to closely and systematically investigate each actor's discursive style, and make syntheses and comparisons. I cannot be entirely sure

[22] I will triangulate my interview findings with document analysis to determine whether actors' accounts of their own behaviour are consistent in other settings.

my qualitative interview design will produce the output I desire, but the methodological choices I have made are intended to ensure the empirical ground I am going to reach is in accord with my research objective and epistemological stance: to understand the patterned characteristics of members of the particle physics community in their constructions and reconstructions of the value and importance of particle physics for a non-particle-physicist audience. Later, in the data analysis section, I will explain in more detail the necessity of generating open-ended and interactive interviews for EIDA. Next I will clarify my interview collection and generation process, in which each step had to be taken carefully in order to manage the quality of data produced in each interview.

Sampling and Getting into the Field

To study how key actors within the particle physics community interact with current science-policy trends, my interview generation process consisted of two stages: interviewing the key actors within the particle physics community–particle physicists; and interviewing emerging actors within this research community–knowledge transfer (KT) officers—who embody the contemporary science-policy agenda on impact and social responsibility. As EIDA pays attention to language-use, discursive style, storytelling technique and conversational transition in the construction of a fact or account, I have chosen to keep my interview sample size small, enabling me to generate longer in-depth interviews within the limited fieldwork time in a PhD project[23]. Therefore, at the first stage of the interview

[23] The research design and ethical review of this thesis were approved by the first-year progression board of the faculty in July 2015.

generation process (between February and June 2016), I concentrated on interacting with the particle physics research group at the University of Edinburgh.

<Edinburgh>

Being in the same university with my particle physicist interviewees facilitated the arrangement of interviews. Moreover, the particle physics community at the University of Edinburgh is unique in relation to the Higgs boson, as this is not only the institution where Emeritus Professor Peter Higgs proposed his theory of the Higgs mechanism but also an active participant in European HEP research at CERN. To generate my interview sample at Edinburgh I employed three kinds of nonprobability sampling: purposive, snowball and quota (Blackstone, 2015). In other words, I classified particle physicists based on their research areas and positions, contacted particle physicists by myself or through their colleagues, and constantly monitored the diversity of my sample.

I started to construct my sample by studying the research profiles of particle physicists according to two-dimensional criteria: career stage/vertical and expertise/horizontal. Career stage is important because researchers at different levels will have different work experiences shaping their interactions with contemporary science-policy agendas. For instance, seniority might affect how sophisticated value claims are, since senior staff members have relatively more experience in administration and grant applications. Hence, in the phase of data analysis, I will study whether or not the discursive practices used by senior staff are more rehearsed than spontaneous. My interviewee sample included PhD students and postdoctoral fellows, and mid-level, senior and retired particle physicists. Furthermore, the practical benefit of categorising my interviewees according to their career status is that I can pilot my interviews with young particle physicists, with whom I am more comfortable practising the terminologies of particle physics learnt from my desk-top research. I believe this preparation is crucial for generating spontaneous, interactive and in-depth interviews with senior particle physicists.

Given the particle physics community has a highly specialised division of labour, which determines an individual's outputs and their degree of reliance on technology, the horizontal dimension of expertise also requires attention. Consequently, I have classified the particle physicists into theorist, experimentalist, instrumentalist and industrial scientist according to their research profiles on the University's website[24]. With this list of potential interviewees, I sent out interview invitations via my university email account, which is less likely to be classified as a spam sender. Nonetheless, it was not mandatory to respond to my interview request and I did not initially get a high response rate. Thus, I had to rely on my personal network and the recommendations of my initial respondents to secure more interviews.

<CERN>

At the second stage of interview generation, I targeted actors within *CERN Knowledge Transfer Group* (CERN KT). With the world's largest experimental

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[24] 'Phenomenologist', a role that lies between theorist and experimentalist, is an emerging expertise within the particle physics community. However, the role is not common in the Edinburgh community and therefore I did not have a chance to interview a phenomenologist for this thesis.

facility for particle physics research, the LHC, CERN has the most scientists and engineers working together around the world in particle and high-energy physics research. Thus, it has the potential to gather the most political discourses reflecting on its value and importance for both science and society. Moreover, guided by the *European Strategy for Particle Physics* (the Strategy) (CERN Council, 2006, 2013), CERN is emphasising the importance of actively delivering the wider benefits of particle physics research to society more than ever, and transformed its Technology Transfer Group into the current CERN KT around 2010. Knowledge transfer activities for particle physics research do take place in the UK (STFC, n. d.), and are perhaps closer to the experience of my UK-based particle physicist interviewees. In fact, in between the first and second stages of my interview generation, I considered the *Scottish Universities Physics Alliances* (SUPA) as a potential object of study, as a number of interviewees had mentioned SUPA's promotion of knowledge exchange and industry engagement. However, after conducting three pilot interviews with SUPA members, I realised the SUPA KT team is not large or organised enough for me to sample a list of interviewees of a comparable size to the list of my particle physicist interviewees.

Despite the fact that CERN KT is based in Geneva, Switzerland, the majority of my UK-based particle physicist interviewees are in constant contact with the CERN facilities to exchange experimental data and information on instrument development. Since CERN is indispensable to my particle physicist interviewees, I believe a focus on CERN KT in the second stage of interview generation is appropriate. Furthermore, I assume that choosing CERN KT as my object of study will provide me with greater analytic strength than remaining in the UK for the entire fieldwork: I can not only secure a broader view on the ecosystem of the particle physics community, which relies on large external facilities for experimentation, I can also extend my research from a university-wide particle physics community to an international particle physics research facility. Of course, CERN KT cannot represent the entire research community; therefore, in the later document collection and analysis section (more discussions in sub-section 3.3.3: p. 108), I will explain how the collection of documents from the Strategy enhances my understanding of European and international particle physics communities.

As a team dedicated to delivering information on the wider impact of particle physics on society, CERN KT is open to public enquiry with contact information on its official webpage (https://kt.cern/about-us). I received a positive response to my interview request from one of the CERN KT section leaders after ten days, as the team regarded participation in my research as a wider form of knowledge transfer (Yeh 2015, personal communication, 12 May). I replied with an information pack, which included an introduction to the thesis project, my fieldwork plan and a consent form. In the passage below, I will explain the sampling strategy I applied to CERN KT. However, firstly I will address the suitability of CERN KT as my research object, given that its actors are familiar with my topic and thus may not provide spontaneous answers. Being aware of this situation I have attempted to use plain language throughout my interview guide (see Appendix B: p. 249), avoiding all technical terms relating to current science policy agendas. Also, during the interviews and in the data analysis phase, I will compare repertoires that appear more and less rehearsed by taking into account the emotional tones, auxiliary words, repetitiveness and cohesion of discourse.

My interview request was agreed to at the higher-levels of CERN KT, therefore I did not require personal networks to approach CERN KT officers and employed purposive and quota sampling to plan the list of interviewees[25]. CERN KT has around twenty staff members from various educational and disciplinary backgrounds and is responsible for a diverse range of knowledge transfer activities. Therefore, I also planned a quadrant-like sampling strategy for the KT interviews, in which I sampled KT officers vertically and selected horizontally from their various job descriptions. In brief, the list of CERN KT interviewees contains officers, section leaders and the group leader, and in expertise, measured by highest degree, including biomedical sciences, physical sciences, engineering, computer science, law and business. Moreover, since my thesis investigates the strategic level of European particle physics research, I also sent interview requests to the Director-General's office and the Council Secretariat of CERN, and, after a long wait, received positive replies. Hence, alongside interviews with CERN KT personnel, mainly professional services staff rather than particle physicists, I was able to link the KT group's worldview with that of the particle physicist group through interviews with CERN executives.

Conducting Interviews

I regard both the first and second stage of interviews as 'elite' or expert interviews (Smith, 2006: 643, Harvey, 2011: 431), as my interviewees are highly educated and work in higher education or an international research institute. I therefore required substantial preparation to ensure fluency during the interviews.

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[25] There is one exception – No. CERN 2 interviewee – who was a new staff member at the time I visited CERN and was introduced to me by other KT interviewees.

Having taken an online course on the discovery of the Higgs boson at FutureLearn[26] during my Master's research, which also related to the Higgs boson, since the beginning of my PhD programme I have also established the habit of reading *CERN Courier*, the monthly journal of international high-energy-physics, and have followed the social media outputs of major particle physics communities. Furthermore, before each interview I would study the web profile of my interviewees in detail, memorising the specific terminologies of their expertise and tailoring the general interview guide according to their backgrounds. I have found that this preparatory work has enhanced the trust-relationship between me and my interviewees, and to a certain extent mitigated the inherently imbalanced power-relationship of elite interviews (Smith, 2006: 643). In situations where I encountered scientific accounts of particle physics that were beyond my understanding, I let my interviewee know and asked for more explanation. These were also great opportunities for me to steer the interview to more discussion on the value and importance of my interviewees' research or project.

Face-to-face interviewing is undoubtedly the best way to generate data for this thesis, as my concern is interactive discursive practices and situated negotiations with regard to the value and importance of particle physics. Open-ended and qualitative interview design also requires the body language or physical attendance of the interviewer to encourage interviewees to respond. However, if conducting the interview face-to-face was not possible, I considered web-cam use an acceptable alternative and the closest form to face-to-face. Moreover, since I aim to encourage in-depth discussions about the motivations, assumptions and

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[26] A digital education platform run by the Open University in the UK.

expectations of my interviewees, which I assume are interconnected with their value claims and behaviours, the preparatory work I have carried out serves as an icebreaker to 'probe and prompt' (Fielding and Thomas, 2001: 128) their opinions. I did not make the interview guides I prepared available to my interviewees prior to interview, but did detail the basic directions my interviews would take in invitation letters or an attached information pack. If my interviewees were to prepare for the interview too much this could inhibit ethnomethodologically interesting spontaneous responses. I also avoid using technical policy terms such as 'impact agenda', 'responsible research and innovation', 'public engagement', etc., to generate interviewees' natural responses to simple question about the value and importance of particle physics research.

To provide my interviewees with a comfortable space for in-depth discussion and ensure the quality of audio recording, the interviews were mainly conducted in interviewees' offices or private meeting rooms. Occasionally, upon the interviewee's request, the interview was held in a café or canteen[27]. I provided the interviewee with a hard copy of the consent form[28] before commencing with the interview, which they could sign whenever they wanted. With the interviewee's permission[29], I employed both a mobile device and an audio recorder to record interviews and informed them whenever I started or stopped recording. Meanwhile, as my interest lay in studying interactions taking place during the

[27] In such cases I would use GoldWave – an audio editing software – to reduce background noise on the recording file.

[28] The digital file of the consent form had already been attached to the invitation email.

[29] One interviewee did not agree to be recorded. Therefore, with their permission, I analysed the field notes I took during the interview instead.

interviews, including emotions and bodily expressions that may not be recordable by audio devices[30], I made field notes immediately after the interviews, noting my overall impression for future analysis.

I conducted sixteen interviews with Edinburgh-based particle physicists and thirteen with officers and higher-level directors at CERN, a total of twenty-nine qualitative interviews. The average length of interviews with Edinburgh-based particle physicists and one CERN higher-level particle physicist[31] was an hour and a half, while interviews with CERN KT and other officers were around one hour long. As a number of my interviewees requested anonymity, I allocated all interviewees a number. The list of interviewees can be found in Appendix C (p. 251) and Appendix D (p. 253). I uploaded the audio files to a laptop and online drive, both password-protected, as soon as possible after the interviews. On returning to my office, I scanned a copy of the signed consent form and included it in a 'thank you' letter for the interviewees. The scanned consent forms were then stored on the same password-protected devices.

With the help of *Express Scribe*—transcribing software that enabled me to manage and transcribe the audio files with ease—I transcribed all the interviews and stored the transcripts in the same spaces as the audio files. To facilitate a constructivist-and-ethnomethodologist-inspired discourse analysis, in which discourse is regarded as practice and interaction, I transcribed verbatim and included

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30 I did not plan to film the interviews as this might have intimidated my interviewees and prevented them from elaborating on their personal opinions.

31 An interview with another CERN higher-level individual (anonymous) was only five minutes long due to their tight schedule.

interviewees' pauses, hesitations and emotional reactions, such as laughter and sighing. Since I and the majority of my interviewees are not native English speakers, quotations that appear in this thesis were proofread by a native English editor and then double-checked by myself. Some of the interviewees requested the chance to check their transcript, and therefore I contacted them again following transcription. Although most of the interviewees had no opinion about their transcriptions, both higher-level directors at CERN had concerns: one urged me to use what they had said carefully (Yeh 2016, personal communication, 4 October), while the other extensively amended their transcription (Yeh 2016, personal communication, 15 November). Although this meant these two interviews were of limited use for EIDA analysis, these interactions with higher-level directors at CERN firmly demonstrate their wariness when making claims regarding the value and importance of particle and high-energy physics research. Furthermore, a number of interviewees requested I dispose of their audio files and transcriptions on completion of this thesis. I will carry this out after my viva.

3.3.3 Document Collection

The official CERN website allows public access to documents relating to the *European Strategy for Particle Physics* (the Strategy) (read more in section 1.3: p. 38). These documents include not only the official announcement of the Strategy but also the planning group's preparatory documents, containing minutes of the preparatory group's meeting, 'briefing books' for drafting the Strategy and deliberation papers. I regard these preparatory documents as an extremely useful resource for me to study community-wide discussions over the value and importance of particle and high-energy physics research. Moreover, since these documents present strategic planning by the European particle physics community, they can be understood as part of the research community's interaction with the contemporary science-policy agenda. I therefore collected and analysed these preparatory documents, for comparison with data generated by the interviews.

Although it is essential that social researchers not assume documentation reflects reality and take the multiple practices that finalise the text into account, these documents are the closest I will be able to get to in-house strategic discussions by the particle physics community. Hence, to expand the arguments in my thesis beyond reflection on the interview setting alone, I decided to also apply EIDA to the Strategy preparatory documents. I will now discuss the properties of these documents along with the focus of my document collection and analysis in detail.

The planning process of both the original and updated Strategy lasted almost a year in total. Between 2005 and 2006, and 2012 and 2013, the CERN Council's preparatory group held preliminary meetings to organise symposiums held in Europe and open to all international particle physicists [32]. The Strategy's preparatory group was also responsible for compiling a briefing book for the symposium, in which the international trends within particle physics research, as well as strategic opinions from the leading particle physics communities in Europe and around the world, were gathered. After the symposium, the preparatory group and other delegated and nominated European particle physicists drafted a deliberation paper for the Strategy. This was then submitted to the CERN Council

[32] There were also public lectures for the general public.

for approval by particle physicist and governmental representatives from CERN's member and associate states. The official Strategy statement and a more accessible brochure were to be published after unanimous approval.

I started an initial reading of these preparatory documents before creating my interview plans (between September and December 2015). The briefing books – the two largest documents – contain the most discussion about the value and importance of particle physics research. Both books are around two hundred pages long and contain over ninety thousand words. Attached to the 2006 Briefing Book are one thousand more pages containing original advice from individual particle physicists, universities, national research institutions and international consortia[33]. I therefore decided to target my analysis on the briefing books. There were two stages of the document analysis: one I classified as preliminary and part of the document collection process, while the other was integrated into EIDA. Before providing a detailed explanation of EIDA, I will clarify the first stage of document analysis.

Versions of Value Claims in the Documentation

Having read the two briefing books from a constructivist standpoint, I discovered that these documents categorise the value and importance of particle physics and HEP into different chapters for detailed discussion. In my analysis, I renamed these chapters/categories as follows: 1) scientific value; 2) social and cultural value; 3) material value; 4) profession-related value. With the help of the

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[33] According to the minutes of a preparatory group meeting, the 2013 Strategy Update also called for input and recommendations from the community, but these were not attached to the 2013 Briefing Book.

qualitative coding function of the AntConc software[34], the concordance and collocation analysis of the keywords related to my research questions, I coded the common discursive styles of each category. The major themes of the discursive styles are coded as follows in Table 1:

Table 1. The values of particle physics research. Source: (Åkesson et al., 2006, Aleksan et al., 2013)

Category:	Discursive Style:
1. Scientific value	a. The generation of new physics, new phenomena, new bosons and new particles
	b. The possibility of extending the Standard Model of particle physics theory
	c. The creation of a more foreseeable future for particle physics research with more data and analyses
	d. More opportunities for knowledge acquisition and new discoveries
2. Social and cultural value	a. An essential part of the culture of the member and associated states
	b. Helping to increase cooperation between nations

[34] I used two laptops to analyse the empirical data for this thesis. As one of the laptops did not have QSR NVIVO software installed, I substituted AntConc, a free software for both text analysis and corpus linguistics. Available at: http://www.laurenceanthony.net/software/antconc/

	c. The representation of cutting-edge research in education
	d. The inspiration for socio-epistemic studies to social sciences[35]
3. Material value	a. Advances in communication and information technology, medical technology, energy and environmental technology and technology for education
	b. Advances in instrument development
	c. The fostering of industrial partnerships and commercialisation of intellectual property
	d. The generation of technology transfer in general
4. Professional human value	a. The ability to conduct both pure and industrial types of research
	b. The general ability to do non-research work, such as the capacity to collaborate with others in large-scale HEP experiments
	c. Problem-solving abilities

Synthesising all the categories and patterns of value claims that appear in the briefing books reveals the wide variety of ways these are framed, including the

[35] Karin Knorr-Cetina's research on the epistemic culture of CERN is counted in the briefing book as a social impact of particle and high-energy physics research. See p. XI–14 in: ÅKESSON, T., ALEKSAN, R., BERTOLUCCI, S., BLONDEL, A., CAVALLI SFORZA, M., HEUER, R., LINDE, F., MANGANO, M., PEACH, K., RONDIO, E. & WEBBER, B. 2006. Briefing Book for the Zeuthen Workshop of the CERN Council Strategy Group. Geneva, Switzerland: CERN.

futuristic and promissory arguments for the scientific value of particle physics and HEP; their intangible benefits for a civilised, intelligent and harmonic society; their tangible benefits for an advanced and prosperous life; and the advancement of human capacity in a wide range of careers motivated by particle physics research. However, it is worth noting that the chapters addressing scientific value are separated from chapters relating to other values. The study and articulation of the other values appears in Part 2 of the 2006 briefing book, and were delegated to CERN KT in the process of the 2013 Strategy update. Therefore, I paid particular attention to the rankings of these value claims. Informed by the distinct discursive style of each value category listed above, I argue that the explanations for different values are separate repertoires, which can be analysed with EIDA. Also, since the briefing books are edited into coherent documents for the purpose of strategic advice, I argue that the transitions between repertoires (value claims) merit EIDA investigation to explore the rhetorical devices used to manage the differences between repertoires. Moreover, given the difference in length between the briefing books and the concise strategic plans for concrete actions, it is important to observe the status of these value claims in the wider narrative with the help of EIDA. Since I regard these value claims and practices as my topic of research rather than a source of information, the above table is the beginning of data analysis rather than the answer to my research questions. This is why I have not quantified the appearance of value claims in each category. In other words, these categorised value claims are spaces for me to apply EIDA, and therefore investigate interactions between discourse and its context to gain a greater understanding of why different values are mentioned and articulated in different situations. In the next section, I will explain the EIDA process applied to both the documentation and my interview data.

3.4 Ethnomethodologically-inspired Discourse Analysis (EIDA)

In addition to the value claim categories identified in the Strategy briefing books, I am still open to any construction of the value and importance of particle physics that appears in the interviews but was not mentioned in documentation. I believe the similarity or dissimilarity of interview transcripts cannot be understood through quantitative analysis, as every interviewee has their own language-use, style and topic of interest. To do so, I transcribed all the interviews myself and read through them with the help of another software program that supports qualitative data analysis, QSR NVIVO (v10). I coded all the interviews and created nodes that categorised justifications for the value and importance of particle and high-energy physics research in the transcripts. Some of these are similar to those in the briefing books, others are not. In my empirical chapters, however, I will chiefly discuss the discursive and narrative patterns of value claims made in both documentation and interviews, and only identify major distinctions between interviews and documents when the use of a distinctive category is widespread amongst interviewees. Furthermore, as my interests are the reasons for making these value claims, and the contexts in which they are made, the most important part of the NVIVO coding stage is to explore linkages between value claims and interviewees' accounts of themselves, their interests, their responsibilities, their community and the wider environment. Inspired by ethnomethodology, I regard these discursive practices as actors' common knowledge about what is useful, acceptable or appropriate in communicating their own values with others in a shared discursive context.

Consequently, running ‘Matrix Coding queries’ in NVIVO provided me with an overview of the frequency of association between the nodes of classified value claims and the nodes of different discursive contexts. Table 2 below depicts the result of one such query:

Table 2. One result from the matrix coding queries in NVIVO 10

Matrix Coding Query - Results

	A : physicists' interests- ...	B : describing the pp community...	C : the social context of KT ...	D : reacting to science policy
1 : cultural value	9	7	9	19
2 : material value	2	4	1	5
3 : scientific and philosophical value- k...	17	42	3	6
4 : social value (i.e. nuclear controversy)	0	0	1	1

I used the same cross-tabulation technique to investigate the association between interviewees’ attributes and the results of matrix coding queries, such as differences between particle physicists and knowledge transfer officers, between theorists and experimentalists, between early-career and mature scholars, between different managerial positions, etc. The numeric results in the matrix coding queries are the preliminary findings I can investigate further and compare the discursive practices of different interviewees, or within different topics of discussion. I then applied EIDA to scrutinise the contents of value claims and patterns of their appearance in interviews. In order to understand the patterned characteristics of these discursive interactions, I systematically analysed the actors’ language-use, discursive patterns and narrative structures. In the following passages, I explain the methodological framework I have designed and applied for this interview analysis, which is guided by the EIDA proposed in my literature review (read more in section 2.5: p. 76).

My methodological framework has three steps to study vocabularies, patterns and structures of discourse separately. I regard these dimensions as the points, lines and planes of discourse, with which actors construct their worldviews or social realities and communicate them to others. Hence, firstly, I identified common usages of words and phrases in the interviews and examined their implications as assigned by different interviewees; in this way, I can look for connections between the independently generated interviews. At this stage, I relied on both my qualitative reading of transcripts as well as the text search and word frequency test by NVIVO. My analysis required a mixed-methods approach at this point as the meaning of frequently appearing words or phrases may vary in different contexts and thus needs interpretation. For example, the adjective 'fundamental' often appears in discussions about value and importance, and thus requires contextual analysis. Likewise, different but similar words or phrases may carry the same meaning depending on the habits of language-users and therefore also require qualitative analysis. For instance, both 'curious' and 'inquisitive' are used to describe one's child-like curiosity. Since I agree with Mulkay (Gieryn, 1983: 783), who suspect that scientists' vocabularies indicate their ideologies of science, I investigated the relationship between justifications for the value and importance of particle physics, and the underlying assumptions of these justifications. This study of vocabulary-use serves as a basis for me to study the patterns and structures of the discursive constructions that shape the value and importance of particle and high-energy physics research.

Secondly, as my research questions and interview guides derived from an intention to study the different discursive reactions of members of the particle physics community in response to different queries or expectations, the detailed ways in which actors manage these through discourse are at the core of my analysis. Hence, at this stage, I focused on analysing the patterns of value claims that coordinated with more than one expectation, and paid attention to interviewees' change of language-use, style and content between different claims. This process is mainly interpretative as I followed one value claim to another, and distilled the common discursive patterns from the individual discursive characteristics of each interviewee. Nevertheless, the second stage of my interpretation is not arbitrary and is guided by EIDA, generally informed by Gilbert and Mulkay's analysis of scientific discourse (1984). Therefore, I analysed the interviewees' empiricist and contingent repertoires used to construct the credibility of their value claims in different discursive contexts, such as the evidence of technological advancement relating to particle physics and HEP, and the cultural importance of particle physics and HEP in inspiring people. Furthermore, since Gilbert and Mulkay (Ibid.: 69–81) suggest that the combined usage of the empiricist and contingent repertoires leads to asymmetrical accounts that support a certain stance, I analysed the stance of my interviewees when making their value claims for particle physics research as they were confronted with different expectations. I also noted any rhetorical device used to manage possible discursive inconsistency in asymmetrical accounts, such as the rhetorical device of humour and the 'truth will out device' (TWOD) introduced in sub-section 2.5.2 (p. 80). At this stage, non-verbal information gathered in the interviews – such as laughter, sighing, hesitation, changes in volume and tone, etc. – was considered in combination with verbal communication. The reason why I analyse the difference between discursive construction and the expression of an experience in chapter six only relates to the characteristics of the KT officers: they are cross-boundary actors who not only participate in the culture of the particle physics community but also observe this culture.

By identifying the patterns of value claims made by members of the particle physics community in response to my queries and external expectations, I believe this thesis can evaluate the interaction between contemporary science-policy agenda and the way values are talked about within the particle physics community. However, aside from analysis of the rhetorical devices scientists employ in order to manage the difficulty or paradox of accounting asymmetrically for a stance, Gilbert and Mulkay (1984) do not provide a clear method for understanding the discursive embodiment of 'stance'. To counter this, I found a methodological framework formulated by Myers (1996) for studying the hierarchical form or status of claims. This methodology assumes that the placement of evidence in the construction of knowledge claims is also a way to interact with an audience. Consequently, the third and final stage of my discourse analysis focused on the placement of different value claims in my interviewees' overall arguments. With this vertical perspective on the structure of discourse added to the horizontal view of the interchangeability between empiricist and contingent repertoires, I believe the stance or attitude of the particle physics community in response to external expectations can be clarified. As yet, I have not come across any other methodological framework that similarly integrates the horizontal view of Gilbert and Mulkay's discourse analysis with Myers' vertical analysis of the hierarchical arrangement of discourse in research on the construction of the stance and status of science. From studying language-use and discursive flow to the hierarchical structure of argumentation, I regard the value claims constructed from these elements as the negotiations carried out by members of the particle physics community in reaction to societal expectations and science-policy agendas.

To clarify, the 'interactions' I mention in the above paragraph refer to communications between my interviewees – members of the particle physics community – and myself, representing a non-member of the particle physics community. That is, although I have separately interviewed two subgroups of the particle physics community, I cannot and do not intend to analyse interactions between these subgroups. Instead, I will compare the patterned and possibly different interactions they produce with external queries and expectations. Also, I assume that value claims in a written format are also a type of negotiation and interaction with external readers, and also deserve the scrutiny of EIDA. Hence, while analysing the interview data, I also applied EIDA to the value claims I categorised from the Strategy briefing books and studied the language-use, changes of style and content and discursive structures of these value claims. It is inevitable that secondary data are more distant from actors' sense-making processes than primary data such as interviews. Nevertheless, applying EIDA to the Strategy is a methodological step in triangulating and generalising my findings from interview analysis. In this way, I can not only research the characteristics of value claims in interviews but investigate the wider communicative patterns of the particle physics community, epitomised to a certain degree by these European-wide strategic documents. To clarify, the combined analysis of multiple data sources does not solve the non-generalisability of small-sample, constructivist and ethnomethodologist inspired, qualitative research, but does go some way to mitigating the problem. After the following three empirical chapters on my findings from interview and document analysis, I will discuss the possibility of connecting this research with a large-scale mixed-methods linguistic approach in the future, thereby expanding the validity of EIDA (more discussions in chapter 7: from p. 221 on).

Finally, it is worth noting that, since I am not only concerned with discourse and representation in isolation but also their cultural influence on the members who own and use them, in the final part of my empirical analysis I will move beyond the application of EIDA (section 6.3: p. 200). That is to say, I intend to further study whether the discursive characteristics identified by EIDA are experienced by the members of the particle physics community. To search for this kind of experience, in section 6.3 I carefully distinguish discourses with the features of EIDA from those that lack such features but are relatively more straightforward. Again, since my methodological stance lies in the middle ground—dealing with the relatively stable social realities constructed from discourses—I consider this restricted use of EIDA to be appropriate. To clarify, my concern about the tension between the inquisitive and practical interests of the particle physics community is not a request of the community to predict the future benefits of its research. Rather, my aim is to understand more about how this culture-in-tension might affect the daily practice of KT officers at CERN. To gain this understanding the analysis in section 6.3 is not guided by the ethnomethodologically-inspired discourse analysis (EIDA): instead I focus on discourses that contain no obvious management of the particle physics community's image. I believe these reveal certain social realities (subjective feelings and experiences) within the community. In the discourses discussed below, there are no transitions between repertoires, rhetorical tools connecting repertoires, or hierarchical narrative patterns.

Chapter 4

Representing the 'Worth' of Particle Physics in Interviews

In this chapter, I investigate the different discursive styles that my particle physicist interviewees employed in response to my interview questions. Two major aspects are examined: 1) The autobiographic and comparative accounts of the epistemic status of particle physics (section 4.1. and 4.2.); and 2) The alternative discursive context in which the epistemic status of particle physics is accounted for less assertively (section 4.3). Furthermore, I will identify the major rhetorical techniques employed in these accounts, and map out the linkages and transitions between different repertoires (section 4.4). Ultimately, I will demonstrate that this variation in discourses is systematically guided by a hierarchy of interests: a common and stratified opinion about the motivations behind different types of research (section 4.5).

4.1 The Autobiographic Account

In my interviews with particle physicists, the reconstruction of each individual's past, whether in response to my questions or spontaneously introduced by the interviewee, was a way for them to explain the motivations behind their research. Half of my particle physicist interviewees, including both young and mature individuals, as well as theorists and experimentalists, accounted for their career choice by depicting what kind of person they had been since they were young. Namely, eight out of the sixteen particle physicists I interviewed cited their childhoods to account for going on to study particle physics, or their decision to become a particle physicist. I argue that we cannot assess from the interviews whether these childhood memories are accurate or not. However, the recurrent reconstructions of childhood indicate the discursive importance of a child's innocent curiosity to particle physicists. Here are three examples:

> No. 2: I was fairly inquisitive, and I used to tear my toys apart on Christmas day *[laugh]*. I guess the difference is, after a lifetime in science, I can now put some toys back together again.
>
> No. 8: It's a question which I had long before, even when I was a kid *[pause]*, I was trying to find out 'How does it (*matter)* work?' *[Pause]* so basically, it's a continuation of that.
>
> No. 9: I think my interest in particle physics had already started at school. I was always very interested in the way that matter was constructed.
>
> (Interview Nos. 2, 8 and 9, *italics* added)

The images described by these three particle physicists of themselves as children are extremely similar: all were inquisitive and curious about the composition of things. In these discursive contexts, such young images not only have a temporal-and-spatial-specific implication, but describe these particle physicists' personal traits as lasting *'a lifetime'* (Interview No. 2), or as continuous and constant. In other words, I argue that this déjà vu of particle physicists is a way of illustrating their personalities as inquisitive scientists rather than relating historical fact. Very few details were disclosed before making the swift discursive shift to the present day. The three quotations above by no means exhaust the ways in which particle physicists' childhoods were recounted. Childhood or teenage hobbies of reading popular science books were mentioned (Interview No. 4, 5, 10 and 14), as were the attending of public outreach events or lectures on elementary physics (Interview No. 8, 10 and 13). While each particle physicist depicted his or her childhood differently, I argue that these stories have the same discursive emphasis: identifying the appeal of particle physics with a child's naïve curiosity. In addition, no technical details of particle physics appear in these repertoires. Thus, I argue that referring to childhood is also a communicative technique for particle physicists to explain themselves in a manner accessible to non-particle physicist audiences, who can then make associations with their own childhood memories or widespread cultural representations of children's open-mindedness.

Nevertheless, this association does not provide a clear explanation for the causal relationship between being a curious child and studying particle physics. In other words, particle physics research is a specific disciplinary or career choice, while being a curious child could lead to innumerable careers. Particle physicists therefore require additional discursive resources to emphasise the special epistemic role of particle physics in relation to a child's curiosity when they have to compare particle physics with other sciences during the interviews. I detected two distinct repertoires claiming a higher authority for particle physics in curiosity-driven enquiry. The first is a rhetoric that downgrades the capability of other sciences to understand Nature; the second repetitively utilises the adjective *'fundamental'* in reverently describing the research objectives of particle physics.

Two particle physicists in my interview dataset, Nos. 9 and 10, commented on other sciences immediately after referring to their childhood curiosity. For instance, No. 9 emphasised the ‘smallness’ that particle physics research can achieve in relation to chemical or nuclear physics research:

> I thought I wanted to do chemistry, because chemistry had a lot of atoms, but it was only in the last year of the school when I realised that it was physics that got you to study what was inside the atom *[pause]*. It was the smallness *[pause]*. And in nuclear physics, nuclei are built up of protons and neutrons, but I wanted to look at protons and neutrons themselves, and what was in them *[pause]*. So, it was always going to the smaller and smaller things *[pause]*. So other things are too big for me, I went really to the smallest things.
>
> (Interview No. 9, *italics* added)

I argue that, in No. 9’s explanation of why she chose to study particle physics rather than chemistry or nuclear physics, the ‘smallness’ of particle physics research is a rhetorical resource to support the correctness of her choice. Through comparing basic physics concepts such as ‘atoms’, ‘nuclei’, ‘protons’ and ‘neutrons’, No. 9 gradually established the superior epistemic status of particle physics. That is to say, in No. 9’s discursive logic, the other sciences – where the focus is ‘too big’ – are less significant than particle physics. Even though the minor use of technical terms has made No. 9’s account, to a certain degree, intellectual and professional, I argue that the scale of research is not an objective criterion for evaluating different scientific approaches. After all, whether or not a neutron is more meaningful than an atom depends on the purpose of research, the research question and the theoretical and methodological approach. A non-particle physicist researcher would have a completely different perspective.

Number 9 was not alone in utilising the apparent ‘smallness’ of the objects of particle physics as a rhetorical tool to justify its importance. Once No. 10 had established the association between her long-lasting curiosity and later choice of studying particle physics, she also compared the scales of research of particle physics and astronomy:

> I just kept reading mostly outreach books, until one day I decided: I do like science, and I think particle physics or like that kind of fundamental physics is cooler than astronomy, because you know *[pause]*, I went from starting wanting to know about the Universe and the big things, to ending up being interested in the very small things, in what things are made of *[pause]*, so yeah.
>
> (Interview No. 10, *italics* added)

I argue that even though drawing comparison into one's account enhances its credibility, the word-use ‘cooler’ in the above quotation, indicates that No. 10’s subjective feeling for particle physics is of greater importance than her rational explanation. Again, arguing that astronomy is less cool than particle physics is ungeneralisable, since an astronomer would be unlikely to agree. Also the reasoning No. 10 presents, that particle physics fulfils her interest in the ‘very small things’, echoing No. 9, may very well be applied to astronomical research. For instance, a gravitational-wave physicist might argue that gravitational wave astronomy, which cannot be explained by the SM, is also the study of extremely small things: the slight outer-space gravitational radiation that indicates the curvature of space-time. In other words, a comparison between the smallness of particle physics and the largeness of other physics research is not an objective explanation; rather, it is a rhetoric utilised by Nos. 9 and 10 particle physicists to justify their contingent career choices.

In addition to Nos. 9 and 10, six other particle physicists in my interview dataset – ranging from junior to senior and consisting of both experimentalists and theorists – made similar comparative accounts that played down the importance of other disciplines. In these cases, the comparisons did not occur immediately after mentions of childhood and children's curiosity, but did appear in the discursive contexts where they justified their preference for particle physics. For example, No. 14, who depicted his younger self as interested in reading popular science books, argued that chemistry didn't deal with *'the sort of fundamental objects'* (Interview No. 14):

> I drifted away from chemistry. Again, because I was terrible at experiments, which is why I ended up going here. I just broke things *[laugh]*. But yeah, it *(in chemistry)* isn't the sort of fundamental objects that you are dealing with. There is always a question in chemistry about, okay, that's as far as we are going to look. We know there are more structures underneath, but it's too complicated to model them.
>
> (Interview No. 14, *italics* added)

As shown, No. 14 began downgrading the explanatory power of chemistry after stating that he was not good at chemical experiments. With laughter, No. 14 theorist's poor performance in chemistry was presented in the interview as an anecdotal memory of his childhood, from which he could then rapidly switch the repertoire to the seemingly scientific reason that he pursued particle physics research. However, I argue that No. 14's interpretation of chemistry is more rhetorical management of his intellectual authority and preference for particle physics than a robust explanation of chemistry. The trace of rhetorical management can be identified from the usage of 'fundamental objects': a general term associated with the subatomic structures that are smaller than and 'underneath' chemical elements. That is to say, No. 14, similarly to Nos. 9 and 10, established the boundary of his justification in favour of the research scale of particle physics rather than that of chemistry or other sciences. In this way, No. 14 could excuse himself from being poor at, or uninterested in, chemistry while still maintaining his epistemic superiority over other disciplines. Nevertheless, if we define 'fundamental objects' differently – e.g. not according to the research scale of particle physics – the same rhetoric could be used to counter-argue about the explanatory power of particle physics, causing endless debate on the intellectual status of different sciences.

4.2 The Comparative Account

As shown above, Nos. 9, 10 and 14 particle physicists all based their justifications of career choice around the microscopic scale of particle physics research, which is relatively smaller than the majority of other sciences. Although these justifications are not objective or always plausible, I argue that they reflect cultural criteria for the high status of a science: a large degree of codification represents how foundational this science is in comparison to other disciplines (Cole, 1983: 112). Namely, particle physicists' fascination with the microscopic study of matter and force, which involves numerous technical terms and mathematical calculations, is a vivid illustration of the high codification or abstraction of their research. Hence, I argue, talking about the 'smallness' of particle physics is a cultural presentation technique for particle physicists to insist on the importance of their research. In other words, even though the scientific terms or concepts of particle physics may not be understood by non-particle physicists, they nevertheless symbolise a hard science that deserves reverence. Furthermore, I argue that the cultural implication of the 'smallness' of scientific research could explain why Nos. 9, 10 and 14 particle physicists did not compare different sciences critically or in any detail: such comparisons are a technique rather than an explanation, through which particle physicists can assert not only the correctness of their disciplinary choice but their superior epistemic authority.

The above quotations reveal some particle physicists' hierarchical opinions of different sciences, favouring their own studies and devaluing other research. The repertoire about the smallness of objects in particle physics is not the only type of rhetoric used to emphasise the authority of particle physics in curiosity-driven enquiry. In addition to No. 14's notion of 'fundamental objects', eight other particle physicist interviewees, both junior and senior, as well as experimental and theoretical, employed the word 'fundamental' to enhance the importance of their own research. For instance, in the two quotations below, both particle physicists labelled their curiosity-driven exploration into particles as a special quest to answer the 'fundamental questions':

> No. 3: There were 'things' *[hesitation]*. Basically, fundamental questions fascinated me. For example, why does the Universe exist? What is it made of? What are the ingredients? And how do they interact?
>
> No. 4: Ultimately the goal and everything I do is actually describing experimental data and understanding sort of the fundamental questions of the world around us.
>
> (Interview Nos. 3 and 4, *Italics* added)

To justify their research to a non-particle physicist (me), Nos. 3 and 4 particle physicists explained their research without revealing many technical details about the theory they support, or the approaches they take[36]. Instead, through the rhetorical deployment of 'fundamental questions', these particle physicists created a simplified analogy between their research and the collective wonderment of all human beings. I argue that such a correlation helps easily and impressively explain to a non-member of the particle physics community what particle physicists do, and why they do it. I also argue that both the rhetoric of 'fundamental questions' and the story of particle physicists' childhoods heighten the relevance of particle physics to society and the world, by depicting the subject as relevant to everyone and everything. However, the deployment of the adjective 'fundamental' has an effect that talk of childhood does not possess: this rhetoric creates an indispensable and comparatively superior epistemic status for particle physics.

However, the adjective 'fundamental' is not only used to demarcate particle physics from other disciplines, it is also deployed to emphasise the higher status of a preferred quest or approach within particle physics. For example, No. 1 particle physicist used it to justify his switch of research interest from the Charge Parity violation (CP violation) to the Higgs boson: *'I felt that it was the most fundamental question that we could answer in nature, as I was really interested in whether the Higgs boson exists, or whether we could find it, or what else we*

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[36] Once I informed the interviewees that I had carried out background research on their research area and expertise they would reveal more technical details. This part of the interviews is analysed in section 4.3 (p. 133).

might find' (Interview No. 1). Thus, through usage of 'the most fundamental question', No. 1 experimentalist depicted his current research subject as the most important possible. Furthermore, alongside use of the word to emphasise the overall epistemic value of particle physics, a number of interviewees also employed the adjective 'fundamental' to describe their anticipation of an improved theoretical framework. For instance, No. 7 noted: *'We really do not know what that more fundamental theory might look like, and we could be in a situation for many years where we don't know'* (Interview No. 7); and No. 15 explained: *'So if a new particle is discovered, that will, at least, give us some sort of indication as to a more fundamental theory'* (Interview No. 15). I argue that the flexible usage of the adjective 'fundamental' in expressing one's hope for improvement of the current research paradigm, as well as in justifying the correctness of one's change in research interest, indicates the rhetorical function of this word.

Therefore, I maintain that when arguing the value and importance of one's stance, the word 'fundamental' is employed as a value claim in the contingent repertoires of the interview excerpts above. As shown, these contingent repertoires can also appear in the scientific discussion. Moreover, I argue that the three repertoires I have identified in particle physicists' autobiographic and comparative accounts – 1) A recollection of childhood curiosity; 2) A comparison between particle physics and other sciences; and 3) Talk of a fundamental pursuit – are used to justify the irreplaceable importance of a particular research interest by creating a universal imagery of the particle physics community. That is, in these discourses, particle physicists depicted themselves as being responsible for the curiosity of all human beings and taking an objective stance towards any specific research question.

Arguing that there is a bias, preference or subjective interest structuring these representations of the particle physics community requires further examination of my interviewees' discourse. Otherwise, one may counter-argue, what I identify as ‘repertoires’ and ‘rhetoric’ may be factual claims that can only be comprehended by the expertise of particle physics. Nevertheless, the justifications for particle physics used in the interviews are dynamic and inconsistent. When I employed technical terms from particle physics in my questions, the interviewees represented themselves and their motives in very different ways from the representations they had made in the above three repertoires. As a result, I maintain that these accounts of motivations for research and the construction of imagery of the particle physics community are more a storytelling technique than a scientific explanation. In the next section, I will provide evidence for this argument by analysing those discourses that are less assertive with regard to the importance and epistemic value of particle physics, and explain why this variation exists.

4.3 Particle Physicists’ Ambivalence

Once my particle physicist interviewees had accounted for their motives and backgrounds, I would proceed to ask more technical questions about their research areas and the general trend of particle physics. This enabled me to examine how they interacted with me in different discursive contexts. Consequently, I found that when I employed technical terms and concepts from particle physics – such as the SM, Beyond the Standard Model of particle physics (BSM), Supersymmetry, String Theory, the direct and indirect searches for the

Higgs boson, neutrino physics and the CP violation; the current and future high-energy facilities such as the ATLAS, CMS and LHCb experiments at CERN, the DESY national research centre in Germany, the Fermilab and the SLAC National Accelerator Laboratory in the US; and international collaboration for future linear or circular colliders – I could encourage my particle physicist interviewees to reflect more on the uncertainties of their knowledge and debates between different research approaches or results. That is to say, the more I used particle physicists' 'vocabularies', the more the omnipresent imagery of the particle physics community in the autobiographic and comparative accounts was replaced by modest reflections on the field. In thirteen out of sixteen interviews with a wide range of Edinburgh particle physicists, I was able to generate more modest discussions about the current status of particle and high-energy physics research, which stand in stark contrast to the superior intellectual status of particle physics articulated in the justifications of particle physicists' research.

Inspired by Mulkay's analysis of the humble accounts presented by Nobel Prize winners at their awards ceremonies (1984), I argue that, despite these modest accounts being contradictory to the previous representations of the research community, accounting less assertively is also a method of managing the epistemic authority of particle physicists. Namely, as I interactively probed and prompted particle physicists to reflect more on their knowledge of the field, these flexible, less assertive interpretations are more suited to dynamically maintaining the credibility of an interviewee's account. Among the eleven particle physicists who either devalued the importance of other sciences, or used the adjective 'fundamental' when emphasising the significance of particle physics research (more discussions in sections 4.1 and 4.2: from p. 123 on), there were only two who did not explicitly mention the uncertainties of their knowledge and the epistemic debates within the field when asked scientific questions. I have detected three types of modest account, through which particle physicists presented: 1) The limited implications of particle physics research; 2) Their uncertainty that Nature can be fully explained by particle physics; and 3) The need for other sciences and approaches in the study of Nature.

Firstly, when asked technical questions about their topics and areas of research, the majority of interviewees expounded on the limited explanatory power of their approaches. That is, in a more dialogical discursive context, many interviewees ceased asserting the superiority of their knowledge, which does have limited empirical foundations. This discursive change was common in interviews with both experts in the Standard Model of Particle Physics (SM) and those beyond the SM (BSM); the two dominant strands of particle physics research. That is to say, there is no 'best theory' in the field for any particle physicist to confidently insist on the superiority of his or her knowledge. To clarify, I am not arguing that particle physicists were inconsistent or acting in bad faith in their interviews but wish to point out their common discursive change in response to different questions and interactions. With this comparison, we can once again examine the face value of particle physicists' assertive claims of their importance and epistemic status. For instance, Nos. 4 and 14, who both used the word 'fundamental' in their autobiographic and comparative accounts to emphasise the significance of their research, also both acknowledged the limits of their knowledge in response to my later scientific questions:

No. 4: Actually, after two years of my PhD, I switched back to working within the Standard Model, and still do *[laugh]*. Because by that point, I was sort of frustrated at *[pause]* if you did anything in these new models, you had to start with a huge paragraph of assumptions, because none of these things has been seen. *[...]* If one or any of those assumptions was wrong, then it wasn't a useful prediction. So there was a combination of that frustration and a realisation of how much was actually still left to do within the particles that we do know about.

No. 14: There was a strong focus on String Theory back in the '80s and '90s. It had been a candidate for the next fundamental theory and had some underlying principles, but it kept predicting things that really weren't physics at all, so it's not good. *[...]* It failed miserably, right? *[Pause]* because it predicted something, the decay of protons, but protons are like very stable objects *[pause]*. You see everything is built out of them, and you can't be without protons to achieve any meaningful theory. So at that point, you are like: 'Ah, we thought we understood something, but actually, we didn't know what we were doing.'

(Interview Nos. 4 and 14, *italics* added)

Number 4 is currently attempting to improve the predictability of the SM but once carried out BSM research, while No. 14 studies BSM Superstring Theory, which only partially conforms to the SM. Therefore, we can observe from the above quotations that the validity of different particle physics approaches is explicitly questioned by their followers. Although accounting less assertively cannot maintain the superior epistemic status of particle physics constructed in the autobiographic and comparative accounts, openly discussing their scepticism about the approaches they have not adopted, or have given up, is also a discursive management technique carried out by these particle physicists: it stabilises their authority in the interviews without directly confronting opposing facts or opinions.

Secondly, two other particle physicists, Nos. 8 and 9, also expressed their doubts about particle physics. In both cases, these concerns came in response to my probing and prompting: I asked No. 8 if he could now answer the questions he had been curious about since childhood, and double-checked with No. 9 particle physicist if her interest in particle physics had really started at school:

> No.8: Me, personally, I understand more than before, but *[pause]* we, as a community, still face big questions *[pause].* One of the big questions is, why the world, as we know it, is made from the matter which we are studying *[laugh]*?
>
> No. 9: Because I had an idea then *[pause]*, which I don't really hold so much now. You know, how the Universe is made? It's made of the little things put together to make the Universe. I don't take that view now.
>
> (Interview Nos. 8 and 9, *italics* added)

In the first quotation, particle physics is not depicted as the epistemic authority that addresses 'fundamental questions', but as *'a community still fac[ing] big questions'* (Interview No. 8). Moreover, through laughter, No. 8 even questioned the underlying assumptions of particle physics. In the autobiographic account where No. 8 claimed his research was a continuation of childhood curiosity (more discussions on p. 137), he did not mention any uncertainty in his attitude towards particle physics. However, I argue that the variation between No. 8's repertoires does not render his claims untrustworthy or examples of bad faith, but shows that they are various interpretations of particle physics he has constructed to explain himself in different discursive contexts. In addition, as noted above, No. 8 paused more than once and pondered carefully, therefore the less assertive claims following the first sentence are more modifications of the first claim than refutations of our previous discussions about motivation. That is to say, an open acceptance of the limitations of particle physics and doubts about the theory the community relies on, still represent the epistemic characteristics of pure enquiry, albeit in a more modest representation.

In the second quotation, No. 9, who argued in her autobiographic account (more discussions on p. 126) that the smallness of particle physics is what differentiates its epistemic value from other sciences, described herself as no longer holding a firm belief in particle physics. I argue that this representational emphasis by No. 9 is similar to that of No. 8: both are declaring their career experience levels and admitting scepticism. As a result, the young and innocent imagery of an inquisitive mind is replaced by the mature and cautious imagery of a still inquisitive mind. Both imageries are used to justify particle physicists' research. After all, most of the particle physicists I interviewed were aware of the argument originating from cosmology that known particles only make up 4% of the matter in the Universe, and there are dark matter and energy unobservable by particle physics. Comparing particle physicists' repertoires in response to different discursive contexts, I argue that the high and irreplaceable importance of particle physics constructed in the autobiographic and comparative accounts needs to be considered a presentational skill rather than a scientific assessment.

Thirdly and lastly, I have found that within the discursive context where the limitations of particle physics were reflected upon, or doubts about the explanatory power of particle physics expressed, a number of interviewees acknowledged the value and importance of scientific input from other disciplines:

> No. 7: Not just particle physics. I also feel that astrophysics could well be another area that, through trying to understand particular cosmology, problems like, you know, 'what is dark matter', and 'what is dark energy'. That might also reveal clues to what a more fundamental extension of the Standard Model would be.
>
> No. 9: You can't only just rely on particle physics. This is probably bigger than physics. You need different people and different specialties to *[hesitation]*. You cannot have one person who looks at one kind of physics and understands all of the rest.
>
> (Interview Nos. 7 and 9, *italics* added)

Neither of these quotations presents an obvious hierarchy of sciences that favours the importance of particle physics and overlooks other approaches. That is to say, the hierarchical accounts that Nos. 7 and 9 had made in their autobiographic and comparative accounts (more discussions on p. 126 and p. 131) were not always insisted upon. Upon realising I was able to discuss some of the technical difficulties of their research with them, these two particle physicists adjusted their discursive stance, becoming more flexible and modest. Nevertheless, I argue that this does not supplant any previous explanations or descriptions of particle physics they had provided. Rather, the interpretative flexibility of Nos. 7 and 9 particle physicists relates to the different interview questions and interactive discussions I prompted. In other words, the decision to represent particle physics as having a superior epistemic status or not is dependent on whether or not it makes sense and is useful to do. Consequently, to examine particle physicists' justifications of the value and importance of their research, we must also consider what kind of discursive context they are responding to.

4.4 Connecting Repertoires

From the discourse analysis presented in the previous three sections, it can be seen that the particle physicist interviewees gave different accounts in different discursive contexts, leading to a changing imagery of particle physics. However, in an interview that was generally about explaining the value and importance of particle physics to a non-particle physicist (me), those who had accounted for their epistemic status less assertively then felt the need to rebuild their epistemic authority. In other words, having accounted for their choices with less certainty, the interviewees subsequently employed rhetorical devices to reassert that particle physics was the most reliable route to a greater understanding of the universe. Six interviewees, including young and mature, as well as theoretical and experimental, having referred to the uncertainty of particle physics knowledge, rhetorically reaffirmed the high epistemic status of particle physics at the end of the discussion thread. In the analysis below, I classify these rhetorical tools into two types: 1) Anticipatory rhetoric and 2) Repetitive rhetoric.

I argue that the key to rebuilding the epistemic authority of particle physics is to rhetorically mitigate the aforementioned limitations and uncertainty. One of the techniques used in the interviews was to mobilise the future possibilities that particle physics may generate, resonating with the function of the 'truth will out device' (TWOD) identified by Gilbert and Mulkay (1984). For instance, Nos. 7, 14 and 15, having made me aware of current problems within particle physics research, employed what I have classified as 'anticipatory rhetoric' to rhetorically guarantee that the particle physics community would eventually gain a greater understanding of the natural world. In the examples of this rhetorical practice quoted below, I have included my probing and prompting:

> Q: Is it a concern when something comes out that can't be explained by the Standard Model?
>
> No. 7: That's almost an opportunity *[laugh]*! That's what we want.
>
> --
>
> Q: So is it possible to have some minor correction or modification of String Theory?
>
> No. 14: I'd like to look at it that way, yes *[pause]*, that's why it's exciting, right? *[...]* Now we've got the opportunity to actually let the physics tell us what it is, and get more data. *[...]* Well *[pause]*, let's see if that becomes true because that would mean that the data has to somehow uncover the principle that we'd never seen.
>
> --
>
> No. 15: Because you are putting in a lot of energy, and then the energy gets converted to matter, eventually you gonna see something *[pause]*, hopefully, that you haven't seen before *[pause]*, like some new form of matter like you haven't seen.
>
> Q: Are you sure that there must be something new?
>
> No. 15: Yeah, yeah, and it's just a matter of finding it *[pause]*. It might be that we can't see it with the LHC because it's not powerful enough.
>
> (Interview Nos. 7, 14 and 15, *italics* added)

As shown, following discussion of their reflexive doubts about particle physics, I asked these interviewees to further reflect on the limited understanding they had gained from particle physics research. In response, Nos. 7, 14 and 15 used positive and hopeful words – ‘opportunity’, ‘exciting’ and ‘new’ – to transmit the possibilities of their research. I argue that the rhetorical tendency displayed in these excerpts suggests these three particle physicists wanted to leave me in no doubt about the definite contribution of particle physics, albeit having themselves just expressed doubts. Moreover, as these particle physicists relied on speculative discourses, I also argue that these anticipatory accounts placed interpretations of the significance or worth of particle physics in a flexible framework. For instance, without specifying how and why, No. 7 theorist replied to my question quickly with a hopeful tone and a simple conclusion, hinting that he and the research community in general were expecting, even controlling the limitations of their knowledge; No. 14 theorist also replied to my question by excitingly betting on a revelatory future, even transforming the ‘unknown’ and ‘unseen’ of the research community into an anticipation of knowing and seeing more; and No. 15 experimentalist avoided admitting possible theoretical limitations by blaming possible technological limitations. In other words, to speak up for their stance and rebuild the epistemic status of particle physics, these interviewees reinterpreted current unknowns of the field into future possibilities through the use of anticipatory rhetoric.

Nevertheless, unlike in the research carried out by Gilbert and Mulkay (1984), I have discovered that to reemphasise the value and importance of particle physics, the interviewees not only mobilised an undetermined future through the use of rhetoric similar to the TWOD, but also referred to their past achievements in what I have classified as 'repetitive rhetoric'. Repetitive rhetoric tends to appear after obvious pauses the particle physicist interviewees made when referring to their limited knowledge. With pauses, particle physicists bounced back to a rhetorical insistence on the epistemic authority of particle physics previously claimed in the autobiographic and comparative accounts, as can be seen in the following excerpts from Nos. 1, 7 and 12:

> No. 1: But one of the things throughout my B *(meson)* physics and CP violation career, is that I've found it's very difficult to find anything new from the Standard Model. Whereas at ATLAS, it's much more sensitive to new physics. Yeah, and I think there is a big question that the Standard Model doesn't answer *[pause]*. But the things it does answer, it answers very well and precisely. So far, after many years of testing it, we haven't found any major problems. We had to extend it slightly to better explain the neutrino sector, but everything is remarkably consistent with what's called the underlying idea of gauge theory and gauge symmetry in fundamental physics.

> No. 7: Because there are things that our theories do not explain yet. But I don't think it's a problem. I think it's just the way that science develops *[laugh]*. You know *[pause]*, basically what we do is, we observe the world, we observe, whether it's a natural world, or social scientists observe behaviour, people, economic systems or whatever it is. We are increasingly getting lots of data which describe all sorts of things, the environment, banking systems, your body and your health *[pause]*. But we don't necessarily have good theories that explain them. The challenge, in a sense, is to go from all that data we have observed to something which *[pause]*, for us, satisfies our curiosity about why or how those systems work.

No. 12: Because in particle physics, you know what particles do, but then hundreds, thousands and thousands of particles, it's not possible to predict in particle physics. So you start to use other rungs of knowledge. But in principle, this *(particle physics theory)* should be *[hesitation]* the part where everything comes from.

(Interview Nos. 1, 7 and 12, *italics* added)

As we can see, firstly, No. 1 experimentalist does not go on to explain what the 'big question' was 'that the Standard Model doesn't answer'. Instead, after a pause, he switched his discursive emphasis to reinforcing the particle physics knowledge he was certain about. Despite referring to his community's previously inadequate explanation of neutrinos, he downplays this limitation through use of the adverb '*slightly*'. This contrasts sharply with his use of the adverb *'remarkably'* to emphasise the underlying robustness of SM predictions. Secondly, after No. 7 theorist expressed his concerns about the limit of the SM paradigm, he laughed off this limitation by using the commonplace *'it's just the way that science develops'* (Interview No. 7), to draw attention away from particle physics in particular, then, with multiple pauses, went on to describe in vague terms the normality and progress of science in general. I argue that the enrolment of other disciplines into No. 7's justification transferred any epistemic challenge to the particle physics community to the entire scientific community, and transformed the interest of particle physicists into that of all scientists, if not every human being. This enrolment prevents the constructed worth or significance of particle physics research sustaining damage. Thirdly, in No. 12's account, although he first acknowledged that particle physics could not explain everything, after a pause he returned to asserting the superior epistemic status of particle physics and described it as the theory of everything. No. 12 also employed a commonplace term – ‘in principle’ – to justify his stance. Like the anticipatory rhetoric discussed earlier, repetitive rhetoric justifies the value and importance of particle physics on a non-empiricist, contingent basis.

Combining my analyses of the particle physicists' accounts, I have found that in their discourse, in response to the broad question about the value and importance of particle physics, the emphasis (not necessarily conscious but at least interactive) is constantly placed on underlining the epistemic authority of particle physics. Therefore, I argue, although various repertoires are used to do this, they all embody a hierarchy of sciences in which particle physics has the highest epistemic status. Moreover, as the top research in this hierarchy of sciences constructed by the particle physicist interviewees is particle physics, I further argue that this hierarchy can be understood as a hierarchy of interests, in which particle physicists prioritise the epistemic value of their community’s research over others. Arguing that there is a hierarchy of interests in particle physicists’ justifications indicates that I need to avoid a partial interpretation: my discourse analysis must also symmetrically investigate what is not of interest to particle physicists in regard to the kinds of value and importance of particle physics. My interview design included asking particle physicists for their views on social responsibility and the wider contributions of their research, as this aspect is insisted on by science policy and research funding agencies. The majority of particle physicists I interviewed were relatively uninterested in public engagement. In the next and final section of this chapter, I will investigate the discursive patterns that suggest this ‘un-interest’.

4.5 Commonplace Impacts and a Hierarchy of Interests

I found that in response to questions about the wider value and importance of particle physics to society, the interviewees tended to represent their community differently from how they represented themselves. All the particle physicists I interviewed were able to provide general answers in compliance with societal expectations, such as the practical applications of knowledge beyond the research community. However, the evidence particle physicists provided in support of their fulfilment of social responsibility and wider contributions, were often not related to, or only loosely related to, their own experiences. Hence, I followed up particle physicists' general accounts by asking for more personal examples and discovered that nine out of the sixteen particle physicists I interviewed were uninterested or had no experience applying their research to socially-relevant purposes. These particle physicists range from junior to senior and across theorists and experimentalists. In the following paragraphs, I analyse how these particle physicists, following my probing and prompting, accounted for their 'un-interest'.

When I asked Professor Peter Higgs[37] about the wider importance of particle physics to society, he quickly gave me a positive reply, and justified this with a few examples of social contributions by CERN and the HEP research facilities, such as the World Wide Web (WWW) and medical physics applications. That is to say, Professor Higgs employed cases not directly related to his own research. For instance, the WWW was invented at CERN after his retirement, and the medical applications are more connected with the instrumentation of particle physics,

[37] Professor Higgs did not request anonymity.

which is not necessarily studied by particle physicists. I went on to ask Professor Higgs if he had ever thought about the wider contributions or social relevance of the theory he proposed, to which he confessed: *'I have no ideas at all about a useful general sense of application of the theoretical ideas'* (Interview No. 13), and then, with laughter, explained: *'I think it's extremely difficult for anybody to use it [the Higgs boson] for anything, because it doesn't last long enough for you to do anything with it'* (Ibid.). I argue that the humorous tone Professor Higgs adopted for the second statement indicates his awareness of how different the imagery of particle physics he was depicting was from the repertoire of public outreach for particle physics he had used several times. That is to say, although Professor Higgs can speak both the mathematical language of particle physics theory and the socially-understandable language about the impact of particle physics demanded by public outreach, he is in fact disengaged from, and inexperienced in, applying his research to wider purposes.

This 'un-interest' in the usefulness of research is not a rare phenomenon only appearing in the senior generation of particle physicists, those relatively distant from the contemporary policy agenda on social responsibility and wider impact. Rather, five out of the nine junior particle physicists I interviewed, who have experienced research assessment at an earlier stage of their careers, can also be seen to express a similar 'un-interest'. In the following paragraphs, I first analyse the discourses of Nos. 10 and 11 postdoctoral fellows, who are deeply affected by the contemporary policy agenda. I then analyse the discourses of No. 12 junior particle physicist staff and No. 14 PhD student, who related both their experiences in grant applications and their opinions on the expectations of funding agencies.

In my interviews with Nos. 10 and 11 post-doctoral research fellows, they used general examples or common repertoires to justify the wider influence of particle physics research on society. Nevertheless, after I asked about their personal experiences in this area, they started to differentiate themselves from the issue:

> No. 10: I just wanted to understand how things work, or what the Universe is made of. You know, 'why things work the way they do'. So my interest was always *[hesitation]* the very fundamental questions. I've never had much interest in working on applications, which are what, afterwards, you end up having to sell the field.
>
> No. 11: It *(application)* is not important to me. Let's say, it's important to society, and for the field to be funded by general society. But for me, it's not that important. I mean, it's *[hesitation]* nice, yeah, but it's not what's making you do this.
>
> (Interview Nos. 10 and 11, *italics* added)

As shown, an obvious change of opinion occurs in Nos. 10 and 11's accounts after my probing. That is, when these two particle physicists had to speak on their own behalf, they stopped engaging with the topic of social contributions and expressed their limited interest in the process. However, I argue that Nos. 10 and 11's discursive change is not a self-contradictory presentation. For instance, the rhetoric used by No. 10 – *'the very fundamental questions'* – returned the interview to the storyline on the importance of pure enquiry. This is the key method many interviewees employed to justify themselves and their motivations in the autobiographic and comparative accounts (sections 4.1 and 4.2: from p. 123 on).

Despite the fact that No. 11 did not use common rhetoric, I argue that the clear separation he made between his own interests and societal interests is also a return to emphasising the importance of pure enquiry. It is intriguing that in regard to the wider importance of particle physics to society, when asked for their personal opinions, the interviewees were prone to defend their own stance or interest rather than societal interests I also argue that the particle physicists' personal opinions offered in response to my probing and prompting illustrate the rhetorical nature of their previous general accounts. The rhetorical strategy deployed by the particle physics community in reaction to external expectations is mentioned by No. 10, as she described the practical applications of research as *'what, afterwards, you end up having to sell the field'* (Interview No. 10). I argue that the rhetorical shield of 'fundamental questions', which prioritises research objectives without practical purposes, enables No. 10 to openly discuss the strategic activity of the research community in regard to wider impacts and social responsibility.

In my interviews with Nos. 12 and 14 I also found that their strategies of presenting research in grant applications and reviews differed from their personal opinions on the responsibility to deliver wider impacts. For example, when I discussed with No. 12 PhD student about his failed grant application for the UK national supercomputing service, he claimed he had learnt from the feedback of referees, and promised in his future applications to pay more attention to the wider advantages of his research, as expected by the grants body (Interview No. 12). However, when I asked about his action plan for fulfilling the wider promises of his research, No. 12 insisted that he could achieve this by publishing journal articles, as the algorithms that he had developed, or was going to develop, would be accessible to others for further applications (Interview No. 12). I argue that No.

12’s justification lacks a clear description of the pathways to impact, which leaves the wider contributions of his research uncertain. Therefore, I further probed No. 12, asking if the lessons he had learnt from the failed application would influence the way he conducts research. He was quick to deny this possibility:

> No, no, not influence. It will just influence how I will *[pause]*. If I have to apply again for this sort of things *[hesitation]*, how to write the proposal, but it will not change my research itself. It gives some constraints to the research, but I think research should be free from them.
>
> (Interview No. 12, *italics* added)

I argue that No. 12’s negative answer to my follow-up question is similar to the discursive change when Nos. 10 and 11 expressed their personal opinions. In other words, following No. 12’s general account in compliance with external expectations, in his personal account he refused to incorporate such expectations into his research. This refusal also indicates the hierarchy of interests held by No. 12, which echoes that of Nos. 10 and 11 and prioritises his own interests over external objectives. Consequently, I argue that the external expectations from funding bodies have only inspired No. 12 PhD student to improve his representational strategies.

The other instance is No. 14 junior particle physicist. Although he did not share with me any failed grant application experience, he did explain how he justified his research proposal to the UK STFC. No. 14 promised in his application that his research could benefit *‘the development of computing methods and the test of the technology we now have in this very extreme environment'* (Interview No. 14). However, throughout this part of my discussion with No. 14, he was unable to clearly define what *'this very extreme environment'* is, and did not show any familiarity with possible wider applications of these computing methods[38]. Instead, in response to my probing for more details, No. 14 theorist switched to claiming that non-theorists have a *'more direct connection with the industry and a lot of what they do is what the impact of your research will have outside of your community'* (Interview No. 14). Therefore, although No. 14 did not directly reveal his 'un-interest' in practising the practical contributions of particle physics, I argue that the pattern of his discourse is still similar to those of Nos. 10, 11 and 12. Namely, these four particle physicists all presented general empiricist accounts that managed (not necessarily consciously but at least interactively) their performances on the social responsibility of research, yet their personal opinions, or contingent accounts, all indicate a limited engagement with the delivery of any societal benefit. As a result, we can observe from the analysis in this section that there are two types of performance in discussions about the wider value and importance of particle physics to society, which I argue, weave a hierarchy of interests common among the particle physicists I interviewed and interacted with.

A question that should be addressed is whether the hierarchical characteristics of particle physicists' justifications only occur in interviews, and if such discursive patterns have been influenced by my interactions. I acknowledge that my findings are contextually dependent, but I also asked my interviewees to reflect on their experiences when explaining themselves and their research to other non-particle

[38] Number 14 theorist did talk a little about working with cosmologists, but had never put this idea into practice. Although cosmologists do conduct research on the *'very extreme environment'* that is different from Earth, this is still a rather far-fetched attempt to explain the wider impact of his theoretical work.

physicist audiences. Although I can never bypass discourse and rhetoric to simply capture reality, I argue that my interviewees' reflections on their wider communicative experiences, have enabled me to determine that the hierarchical characteristics of their accounts exist beyond my interviews, and are also observable in their public outreach practices. To clarify, in examining the particle physicists' outreach experiences, rather than take their reflections on communicative experiences as fact I have focused on the discursive strategies used in wider communication. In other words, I intend to compare the discursive strategies used by particle physicists in their interviews with the communicative techniques they claim to have employed in public outreach.

In the next chapter, I firstly analyse a full narrative arc represented by a higher-level particle physicist, who claimed that he and his team often used such a justification in outreach activities. I intend to show that this narrative arc embodies the hierarchy of interests I detected in this chapter, and has a wider influence on particle physicists' outreach interactions with the general public. Secondly, I triangulate the generalisability of this narrative hierarchy by analysing the interviewees' stated intention to practise public outreach and their strategic discourse on the value and importance of particle physics in the Strategy.

Chapter 5

Representing the 'Worth' of Particle Physics in Wider Communications

5.1 Looking beyond Interviews

My research questions and the interview guides I designed for this thesis (more discussions in chapter 3: from p. 89 on) relate to the wider social relations or social contract of particle physics. Therefore, I aim to look beyond the discursive interactions between particle physicists and myself in interviews and gain a greater understanding of the discursive patterns particle physicists employ when interacting with other non-members of the particle physics community or when handling external expectations. To facilitate comparative analysis and rather than collect another set of data from participating in and observing public outreach by particle physicists, whose topics may vary from occasion to occasion and may not be directly related to the questions I posed to my interviewees, I asked the particle physicists I interviewed about their outreach experiences and techniques. Furthermore, to transcend the internal coherence of interview data and triangulate my findings and arguments in this chapter, I have carried out a discourse analysis on documents relating to the European Strategy for Particle Physics (the Strategy), which represents the wider opinions of European particle physicists.

As a result, I have discovered a complete narrative arc, which was presented in the interview with No. 3 particle physicist and has hierarchical characteristics that resemble the discursive strategy mentioned in the 2006 Strategy briefing book

(Åkesson et al.). Although the complete version of this hierarchical narrative arc was only present in the interview by No. 3 experimentalist, the repertoires and techniques for public outreach described by the majority of my particle physicist interviewees also include some elements of No. 3's narrative hierarchy. Moreover, when I interviewed No. 3, he was head of the particle physics subject group at the University of Edinburgh (UoE) and sat on panels of the Science and Technology Facilities Council (STFC)[39]. The managerial and representative roles of No. 3 particle physicist are evidence of his rich experience in cross-boundary communications.

To understand the common discursive strategy employed beyond my interviews, the complete hierarchical narrative arc presented by No. 3 requires in-depth analysis. In section 5.2, I unravel one by one the hierarchical layers of No. 3 experimentalist's narrative arc for outreach and wider communication, which I then triangulate in section 5.3 with the hierarchical discursive strategy I located in the working documents of the Strategy. In the final part of this analysis, section 5.4, I discuss the intentions and similar hierarchical patterns of other particle physicist interviewees' discourse on outreach strategy. My overall argument in this chapter is that although a two-way and critical public engagement is now expected by policy and funding agencies as a pathway to impact (RCUK, n. d.-a, n. d.-b), the European particle physics community still approaches the issue with a one-direction outreach mentality: what can we do to convince non-particle physicists of the impact or worth of our curiosity-driven enquiry.

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[39] Number 3 particle physicist did not request anonymity and therefore this identifiable information can be presented here.

5.2 The Hierarchical Narrative Arc for Public Outreach

When I interviewed No. 3 particle physicist, it became evident that he was experienced in public outreach and policy advice, and had a systematic communicative strategy. For example, upon hearing my question about how to communicate particle physics to a wider audience, No. 3 quickly started his reflection by noting: *'I think this is a very important question which we discuss quite frequently. For things like this* (the value and importance of particle physics)*, we are prepared to answer'* (Interview No. 3, bracket added). I argue that this opening has two implications: firstly, No.3 is assuring me (also a non-particle physicist audience) that the community actively engages with wider audiences; yet secondly, his reply suggests that the answer the community provides to society is carefully and cautiously constructed. I argue that the subsequent part of No. 3's answer also has this dual property: it is simultaneously a performance and an explanation of his performing skills. In the later analysis, I will investigate both the semantic and stylistic elements of No. 3's reconstruction of his outreach or advisory talk, which, without interruption, lasts for ten minutes.

Furthermore, I argue that the justification for particle physics that No. 3 describes is strategically organised to convince society that particle physics is of the highest critical value to the research community. At the beginning he actively reminded me of the hierarchical layers of his story by saying: *'Let me come to the important one at the end'* (Interview No. 3). That is to say, when analysing the advocacy of particle physics by No. 3, we have to bear in mind that the pieces of justification in support of his advocacy carry different weight. As a result, following No. 3's narrative order, my analysis of his four discursive layers in the passages below is a journey from the auxiliary to the ultimate storyline of the significance of particle physics. At the end of this analysis, I will explain the rationale behind this hierarchical narrative arrangement for outreach and wider communications.

5.2.1 Periphery: Spin-offs

The first layer of No. 3 experimentalist's justification for the value and importance of particle physics is about spin-offs. According to the narrative order decided by No. 3, their status in the justification is marginal. However, he still vividly illustrated the value of spin-offs from particle physics to the wider public:

> One typical answer is, what is particle physics for? It is its spin-offs. When you do fundamental research, things get discovered which you don't know *[pause]*. Now the example I am going to make is, a hundred years ago, there were some very exotic theories, like Schrödinger, Born *[hesitation]*, Einstein wasn't really part of it, who developed something called quantum mechanics. No one in their right mind thought this was ever going to be of any use. But transistors rely on a lot of quantum mechanics *[pause]*. Any washing machine now has something in them: When you push the button, there are some transistors working *[pause]*. So in our everyday life in the Western world, without the laws of quantum mechanics, everything would stop, the world would stop because nothing would work anymore *[pause]*. What comes from fundamental research can be terribly important and can have applications.
>
> (Interview No. 3, *italics* added)

As shown, No. 3 particle physicist interchanged ‘particle physics’ with ‘fundamental research’, and after a short pause, asserted a direct linkage between 'fundamental research' and its unpredictable spin-offs by providing an everyday example: quantum mechanics (QM) inspired transistors. Nevertheless, I argue that what No. 3 is attempting to emphasise is not the transistor itself but the inability of physicists to predict the practical uses of research. No. 3 does not explain the technical details of quantum mechanics that are relevant to the development of transistors (I will provide a technical explanation from history of science studies in the next paragraph); instead, he repetitively articulates the unintentional benefits of fundamental research or quantum physics by saying *'things get discovered which you don't know'*, and *'no one in their right mind thought this was ever going to be of any use'* (Interview No. 3). In other words, the wider contributions of fundamental research or quantum physics are depicted arbitrarily as things that will eventually happen, but cannot be predicted. Moreover, as the narrative flowed, No. 3 left the causal-relationship between transistors and quantum mechanics unexplained, moving on abruptly to emphasise the omnipresence of transistor-based technology.

I argue that No. 3's repetitive usage of 'fundamental research' indicates that his emphasis in this example of spin-offs lies on the self-driven purpose of research, as 'fundamental' is a rhetorical device many other particle physicist interviewees employed in explaining their subjective motivations for research (more discussions in sections 4.1 and 4.2: from p. 123 on). That is to say, although No. 3 experimentalist appears to have provided a robust example of a spin-off from particle physics, the way he elaborates on the invention of transistors indicates his subjective stance. The limited empiricism of No. 3's account becomes obvious once he switches to claim, with several pauses, the omnipresence of quantum mechanics in daily life. However, No. 3's argument rests solely on the contributions made by the transistor to contemporary life, as if the majority of day-to-day demands could be met through this mechanical device. As a result, all the exaggerated style, ambiguous causality and abrupt transition expressed when articulating the spin-offs from particle or quantum physics, have embodied No. 3's positive attitude towards the usefulness of his community's curiosity-driven research.

With regard to the contribution of QM to the invention of transistors, I argue that No. 3's discursive emphasis is not factual. Firstly, QM only provides a kind of description or explanation of the world, and neither determines how the world works nor is solely responsible for the invention of transistors. Although quantum mechanical calculations have facilitated the miniaturisation of transistors, enabling cheap mass production of, for example, affordable household washing machines, the invention and development of transistors not only relied on the theory of QM but electronic technology and the semiconductor (Collett, 2013). Secondly, the concept and technology of transistors were in development at the very beginning of the 20th century, before quantum mechanics, and the equations provided by Schrödinger and Born-Oppenheimer for computing the properties of molecules were fed into this development: Scientists at AT&T's Bell Laboratories (Bell Labs) already had a design for an embryonic form of transistor (Collett, 2013). Moreover, Bell Labs embody the nexus between government funding, research and industry. They are by no means only composed of elementary physicists, nor do they do curiosity-driven research without application purposes. For instance, the first project completed by Bell Labs, the invention of the telephone, had been awarded to the U.S. firm by the French government in the late 19th century, illustrating the complex construction of invention by industry, government and academia (NOKIA Bell Labs, n. d.). With this part of the historical story about transistors, it is intriguing to see that No. 3 did not combine the imagery of the invention of the transistor with the spin-off company that has made a huge economic and social impact through marketable products.

In my interview data set, No. 7 theorist, a senior particle physicist and one of the vice principals at the UoE[40], also used the example of the transistor to illustrate the wider benefits of particle physics. Having rhetorically asserted that this invention had been a breakthrough '*at the fundamental level*' (Interview No. 7), No. 7 also provided no causal details between the transistor and particle physics theory. I therefore argue that, despite Nos. 3 and 7 senior particle physicists intending to provide a practical example of particle physics contributing to society, their shared discursive style is more revelatory of their subjective stance on the contribution of particle physics than their knowledge of the intellectual exchange between particle physics and transistors. To clarify, I have no intention of arguing that the discourse about transistors contradicts reality, since constructivist discourse analysis is not about revealing the nature of reality but the versions of it being depicted. However, in addition to understanding particle physicists' presentational skills, I also want to explain why particle physicists employ the same example and a similar discursive style to justify the practical importance of particle physics. I regard the answer to this – the embodiment of subjective stance – as

[40] Number 7 particle physicist did not request anonymity and therefore this identifiable information can be presented here.

the social tendency when particle physicists are faced with the query about their practical impact.

5.2.2 The Discursive Status of Different Spin-offs

The transistor was not the only example of practical benefits originating from particle physics research related by No. 3. In a second narrative layer, he provided another story about the spin-offs from fundamental research: the invention of the World Wide Web (WWW) at CERN. In the quotation below, No. 3 particle physicist recalls his personal experience relating to the WWW:

> What we have done lately, another example is that the World Wide Web was developed at CERN *[pause]*. I was a post-doc in the U.S. at that time. The first year, the web was really fun. It was only for us, though. But now *[tone raised]*, everything, the world has changed.
>
> (Interview No. 3, *italics* added)

According to No. 3's narrative order, the discursive importance of the WWW ranks above the transistor. I argue that the story of the WWW has three advantages the transistor lacks. Firstly, compared to transistors, the early version of which was invented around a hundred years ago, the WWW is a more recent invention, pioneered at CERN in the late 1980s. Hence, the WWW provides No. 3 with an example of the modern particle physics community contributing to society. Secondly, the WWW was initiated at CERN, with which most particle physicists, including No. 3, have or have had close associations within the search for the Higgs boson or other experimental verifications of the major predictions from the SM. Therefore, I argue that the tale of the WWW is akin to a testimony based on the personal experiences of particle physicists, which strengthens the credibility of impact claims for particle physics. Thirdly, I argue that the WWW has a similar, but even more powerful trait than transistors: it is ‘world-wide’. We can observe from the phrase *‘without the laws of quantum mechanics, the world would stop’* in the first narrative layer, and the phrase *‘but now, the world has changed’* in the second narrative layer, how No. 3 is repeatedly demonstrating the ubiquitous global influence of the particle physics community. Unlike the transistor, a technological part hidden inside electronic devices, the ‘world-wide-ness’ of the WWW and the way it has revolutionised communication in contemporary civilisation is impossible to ignore.

Despite the impressiveness of the WWW narrative, the causal relationship between particle physics knowledge and the WWW in the above quotation is as ambiguous as that between quantum mechanics and transistors. The only evidence No. 3 provides is that the invention of WWW took place at CERN. To construct and operate such an extremely technical high-energy physics facility, CERN is composed of not only particle physicists, but many other experts, such as electronic engineers and computer scientists. Although the WWW was initially invented to enable data sharing and storage at CERN and within the particle physics community, the project had been discussed in computer science since the 1960s. Tim Berners-Lee, inventor of the WWW, is a computer scientist/engineer who only stayed at CERN for a short period of time and was working as an independent contractor when he first proposed the concept of hypertext (Coldham, 2016). Moreover, as briefly mentioned by No. 3, the WWW was not initially freely available to the general public: according to the World Wide Web Foundation (n. d.), it was not until four years later in 1993, that advocates, including Berners-

Lee—who had already left CERN for MIT—finally persuaded CERN to release the WWW source code on a royalty-free basis.

I argue that the justification employed by No.3 in the second layer of his discursive hierarchy is not evidence of a singular contribution to the invention of WWW by particle physics: instead, it reflects a co-construction between the particle physics community's need for an efficient data sharing and storage platform and the efforts of data scientists and other experts in this invention. However, I also argue, for representation purposes, the storyline about the wider impact of particle and high-energy physics research does not necessarily have to relate to particle physics knowledge. The discursive connection between CERN and the WWW, or between particle physics theory and the transistor, is part of constructing a story about the linear model of innovation (Linear Model). I argue that in conversations with non-particle physicists, the familiar concept of the Linear Model allows particle physicists to take a rhetorical leap, which exploits recognition of the long and complex process of technological and economic development that involves multiple actors. Aside from No. 3, the majority of other particle physicists I interviewed also cited the WWW as an example of benefits originating from their field. In total, the WWW example appeared in nine of the sixteen particle physicist interviews I conducted, including the interview with Professor Peter Higgs, who retired before the WWW was invented. I argue that this frequent exploitation of the WWW's invention is a way to representationally manage external expectations and policy agendas relating to the wider benefits of particle and high-energy physics research. To explore the purpose of such exploitation, I will now analyse the rest of No. 3's narrative layers.

5.2.3 Intangible Contributions

After vividly illustrating examples of practical spin-offs, No. 3 shifted the discourse to the intangible contributions of particle physics, implying these were more important than the material impact of scientific research. In the quotation below, No. 3 depicts these intangible contributions by praising the educational efforts of fundamental researchers in general:

> The third example: What is fundamental research good for? *[Hesitation]* it's slightly a tension, but it's terribly important. We here at Edinburgh University and other good universities worldwide, we educate the brightest kids of this generation. I always thought that teaching was terribly important, because for me, basically, I get to do what I like; I get paid for my hobby *[pause]*. One thing I can give back to the *(research)* community is to educate the young students.
>
> (Interview No. 3, *italics* added)

The opening question in this quotation is different from the one No. 3 asked in his first narrative layer: *'What is particle physics for?'* (more discussions on p. 158). Here he is more openly expressing his moral assessment of the value of fundamental research and particle physics. In other words, I argue that No. 3 is declaring that educational contributions exemplify the virtue of scientific research more than its spin-offs. In addition, No. 3 again interchanges 'particle physics' with 'fundamental research', a change that opens up a wider rhetorical space for No. 3 to relate the importance of education; by no means a contribution from particle physics alone.

Although No. 3 affords education a higher discursive status than spin-offs, the direct beneficiaries of particle physicists' educational contributions are a small restricted group: as No. 3 states, he and his colleagues only '*educate the brightest* *kids'* (Interview No. 3). The hesitation at the start of this justification reinforces the 'tension' in talking about what particle physics is good for, and indicates that his argument might not have a wide appeal, despite the fact that No. 3 describes the tension as 'slight' while emphasising that the educational contribution is 'terribly important'. Moreover, as the justification proceeds, No. 3 uses the words 'like' and 'hobby' to describe his motivations for studying particle physics, increasingly illustrating his subjective inclination towards particle physics research rather than any objective need to articulate the wider contributions of the field. I argue that the use of 'like' and 'hobby' does not downplay the epistemic status of particle physics in this discursive context since it is justified by the contribution of teaching and educating. Consequently, as No. 3 moves upwards through his narrative hierarchy, an emphasis on the epistemic value of particle physics becomes increasingly obvious. Nevertheless, towards the end of the quotation, after a pause, No. 3 modifies his previous remark and argues that teaching and education are his contribution back to the research community, rather than society in general.

Teaching and education can indeed be a substantial contribution from research to society. However, I argue that education is more of a rhetorical device for No. 3, with which he can justify the community's subjective research interests. My argument is illustrated by No. 3's conclusion to this narrative layer: '*If Britain wants to keep its place, and to compete with other countries, then we'd better educate our people best'* (Interview No. 3). From this quotation we can observe that No. 3 has made a discursive shift from evidencing the wider importance of particle physics to rhetorically articulating the importance of education through a prosaic, commonplace assertion. This conclusion no longer relates to our topic of discussion, but instead exposes the discursive purpose of No. 3's third narrative layer. My analysis of the final layer of No. 3's narrative hierarchy will clarify his asymmetrical stance on particle physics research.

5.2.4 Motivation Defines Status

Number 3 particle physicist devoted the final part of his public outreach message to explaining the importance of curiosity as motivation. Therefore, I argue that the educational contributions of fundamental research and particle physics, placed between tales of spin-offs from particle physics and an ultimate exhortation for curiosity-driven research, is not a mere example; rather, in this narrative hierarchy, it also functions as the discursive groundwork for No. 3 to shift smoothly to elaborating on the spirit of curiosity-led research. Otherwise, the practical spin-offs of particle physics may appear too distant from the epistemic purpose of particle physics research.

In his final justification, No. 3 asked again: *'What is research good for'* (Interview No. 3). This time, No. 3 declared his answer to be the '*honest*' one (Interview No. 3), implying the closeness between this answer and his personal opinion. Furthermore, the combination of No. 3's declaration of honesty with his preamble to the narrative hierarchy that clarifies the most important status of his final discursive layer, I argue that this layer of justification is what No. 3 experimentalist cares about the most. He firstly explained:

> It is because we are curious. It's not because it makes the world a better place. No, it's not because we can *[hesitate]*. Let me make this example. It was Rob Wilson, the first director of Fermilab. He was asked in front of Congress about Fermilab. He was asked: 'You're building this machine at Fermilab, but what does it

> contribute to the defence of the United States?' His answer was: 'Nothing, but it makes it worth defending.' I subscribe to that.
>
> (Interview No. 3, *italics* added)

Notice that in this quotation the practical contributions of research to society, elaborated on in the previous narrative layers, are no longer regarded as important or relevant. I argue that this shift in No. 3's opinion, completed in a single narrative arc, confirms the rhetorical purpose of his previous justifications. Moreover, I believe the anecdote about Fermilab's founder addressing Congress, which I have come across numerous times during my participant-observations and secondary data collection, is also a rhetorical device. That is to say, although this authoritative claim successfully subdued scepticism from the US Congress, it does not provide robust justification for the worth of this research; instead, it reproduces or reinforces the authority of particle and high-energy physics through a persuasive speech-act. Namely, use of this anecdote demonstrates No. 3's positive attitude towards investing in particle and high-energy physics research, whether or not wider benefits arise. Use of this anecdote also exempts No. 3 from acting in an overly authoritative way as he is merely restating his predecessor's stance.

My foregoing argument is evidenced by the characteristics of the second part of No. 3's final justification, in which he earnestly describes the importance of human curiosity in general:

> Since the beginning when humans started to look at stars, we have been curious. We, for better or worse, rule this planet, and we are not the mammal or the animal which runs fastest, has the biggest paws, or has the biggest jaws. What do we have? We have the biggest brains. As long as there are humans, humans will be curious. At the end, researchers simply *[pause]*. We are curious *[pause]*. Yes,

> I'm very lucky to be able to be curious as a profession, but this is what separates us and countries *[hesitate]*. Then it ties back to *[hesitation]* only countries, which support research and education, can survive in today's world.
>
> (Interview No. 3, *italics* added)

As shown, No. 3 supports particle physics research because of his curiosity, not because it benefits society, and he relates this to general human curiosity, rather than the unique inquisitiveness of particle physicists. Therefore, I argue that this general account reveals the rhetorical function of human curiosity, which can be used to justify any kind of blue-sky research. Furthermore, my research has shown that this articulation of human curiosity leads to a rhetorical dilemma, which also occurred when particle physicists explained their motivations for research by articulating their childhood curiosity (more discussions in section 4.1: p. 123): that is, general accounts are eventually insufficient to answer questions about the specific value and importance of particle physics research.

In his repertoire for public outreach and wider communication, No. 3 did not employ the first rhetorical device I identified in section 4.2 – degrading other sciences – to enhance the epistemic status of particle physics. In addition, the way No. 3 used the adjective 'fundamental' in this narrative hierarchy, which is the second rhetorical device to strengthen the significance of particle physicists' curiosity (more discussions in sections 4.1 and 4.2: from p. 123 on), was not accompanied by an observable exclusion of other types of curiosity-driven research. Instead, No. 3 used 'fundamental research' as an umbrella term/concept to justify not only particle physics but other curiosity-led sciences. This discursive tendency can be observed in this last narrative layer from No. 3's general description of himself and his colleagues as ‘researchers' rather than particle physicists. I argue that No. 3‘s different reaction to the rhetorical dilemma caused by general accounts implies that the two rhetorical devices used by particle physicists to explain their motivations for research are not appropriate when discussing public outreach. Only one of my interviewees, No. 15 experimentalist PhD student, played down the importance of other disciplines (informatics) when accounting for the wider contributions of particle physics research and noted the unique problem-solving skill he had in computer simulations (Interview No. 15). I argue that this singular case might relate to the relative inexperience this young particle physicist has in wider communication and public engagement. After all, degrading other sciences and publicly proclaiming the merits of fundamental research, without robust arguments or evidence, could lead to endless debates with other scientists.

Hence, I argue, in the final layer of No. 3 particle physicist’s narrative hierarchy, he inevitably has to admit that conducting curiosity-driven particle physics research is a privilege that cannot be objectively explained. This rhetorical dilemma and a blunt expression of his own interest also appear in the third narrative layer about educational contributions: *‘I get to do what I like; I get paid for my hobby’* (more discussions on p. 165). Yet again, No. 3 attempts to rationalise his personal preference by returning to commonplace assertions in his conclusion, by politically framing a direct linkage between national competitiveness and research/education. However, I argue that such an apparently persuasive claim is not as empiricist-like as the first two narrative layers, which are concerned with the practical applications of particle physics, but is emotionally interwoven with national pride and our sense of superiority as human beings. There is never a final answer to whether or not curiosity is the most important human characteristic, as this is just one of many opinions.

Looking at all the layers of No. 3’s narrative hierarchy for public outreach and wider communication, analysed in the sections above, an emphasis on the importance of curiosity as a motivating force is ever apparent. As the narrative flows, this becomes more and more visible yet less and less supported by examples. Since No. 3 established this complete narrative arc without my interruption, I argue that the arrangement of his discursive order embodies his overall response to external expectations and science-policy agendas. In other words, to connect with a wider audience and gain their trust, No. 3 particle physicist chose to articulate the importance and contributions of particle physics or fundamental research first, as these would be of concern to a general audience, and to defer his prioritisation of the epistemic value of particle physics. Nevertheless, being placed earlier in No. 3’s narrative arc in no way denotes a higher significance; conversely, based on No. 3’s narrative hierarchy, external expectations are less important than particle physicists' ultimate interest in curiosity-driven research. As a result, I argue that the full narrative arc is a discursive strategy for No. 3 experimentalist to manage both external and internal expectations: it appears to harmoniously integrate divergent expectations, but actually serves to justify particle physics research regardless of societal benefits. Rather than an objective account of the wider importance of particle physics to society, No. 3 particle physicist's complete narrative arc for public outreach and wider communication is the embodiment of his and his colleagues' hierarchy of interests.

5.3 The Community-wide Discursive Strategy

Combining my discourse analysis of interview data with that of the document data, I have discovered that No. 3 is by no means the only member of the particle physics community to employ this hierarchical narrative arc. One of the briefing books of the Strategy[41] (Åkesson et al., 2006) includes a discussion on how to respond to external expectations and contemporary science-policy agendas, in which a dual consideration of both the need to respond to societal demands and the urgent need to consolidate the research community's own stance is recommended. Therefore, I argue that the narrative hierarchy analysed above also reflects the discursive pattern and the hierarchical interests of the wider European particle physics community. From the qualitatively coded text of the briefing book (more discussions in sub-section 3.3.3: p. 108), I have further determined, through application of the ethnomethodologically-inspired discourse analysis (EIDA), that this document is inscribed with descriptions of the hierarchical discursive strategy to be used in managing different types of the values listed in Table 1 (p. 111). I argue that this management epitomises the social relations of European particle and high-energy physics research.

In the passages below, I provide three examples from the 2006 Strategy briefing book (Åkesson et al.) that contain this strategic narrative hierarchy. The first

[41] Although the minutes of the working group meeting indicate there was an internal process calling for input on wider contributions from the research community, no record of this discussion is presented in the 2013 Strategy update: TSESMELIS, E. 2012. European Strategy Preparatory Group: Minutes of the sixth meeting held on Monday, 16 March 2012. Geneva, Switzerland: CERN.

exemplifies how the contributions and importance of particle physics are presented in the strategic document, while the second and third express strategic considerations about the message the research community plans to convey in public outreach and policy communications. In other words, like No. 3's articulation of his communicative experience, these excerpts indicate both the community's discursive performance and the underlying rationale of this performance. To clarify, I do not conclude that these three quotes represent an entire picture of the discursive characteristics of the briefing book, but the implication here is that the hierarchical arrangement of the various value claims about particle physics can also be found in a larger particle physics community, beyond the Edinburgh research group.

Firstly, the 2006 briefing book details the research community's contributions in technological advancement and innovation to society, thereby managing external expectations, before referring to the internal expectations of the research community. For instance, the passage below displays a highly similar discursive pattern to No. 3's narrative hierarchy:

> The technological advancements can find applications useful for society at large, promoting business and general welfare. The innovations created by scientists and engineers working at the frontiers of particle physics can be applied in many fields, such as communication and information technology, medicine, energy, environment and education. Nonetheless, the unalterable reason for doing EPP *(elementary particle physics)* is the science and not the technology–because there are always 'cheaper ways of developing the non-stick frying pan than putting a man on the moon'.
>
> (Åkesson et al., 2006: 162, *italics* added)

In this passage, a wide but vague range of useful contributions from particle and high-energy physics research is placed at the forefront. Although these practical benefits are only briefly referred to, this could, to a certain degree, be said to create an empiricist account. However, once again, taking priority in narrative order is no guarantee of high status. I argue that the key message of this passage is located after the conjunction 'nonetheless': the objectives of the European particle physics community are emphasised by the term 'unalterable reason' and illustrated with a quoted yet reference-less maxim. Moreover, the humour in this maxim results from the juxtaposition of the different cultural statuses of outer-space scientific research and culinary technology: there is no further explanation of practical contributions from the moon landing to justify the high cost of this research. To clarify, I do not intend to undermine justifications of the practical benefits of particle physics theory and research, such as transistors and the WWW, made by No. 3 and others, by taking the maxim about cheaper ways of developing technologies 'seriously'. Instead, the point of analysing this maxim is to compare the adjectives used for describing science and technology, which are respectively 'unalterable' and 'cheaper'. I argue that these two words suggest the European particle physics community's hierarchical opinions about science and technology, in which the former carries significantly more weight than the latter.

Moreover, I believe the use of this maxim is similar to the rhetorical dilemma No. 3 experienced after subjectively articulating the epistemic value of particle physics in the discussion about its wider and practical importance—*'It is because we are curious. It's not because it makes a world a better place'* (Interview No. 3)—That is, the need to fall back on a prosaic argument about national defence. The asymmetrical stance or hierarchy of interests of the European particle physics community also emerges in these Strategy documents. I argue that the passage above embodies the research community's 'un-interest' in applied research, which is wittily 'metonym-ised' into a non-stick frying pan, so common-place that we tend to take it for granted. In comparison, the moon landing project, a human achievement heralded throughout Western cultures, is a noble analogy for curiosity-driven research. I further argue that this humorous and ironic comparison creates a safe discursive space for European particle physicists to express a stance contrary to external expectations and science-policy agendas, as in the reference to cheapness in the development of technological applications.

Due to the briefing books' preparatory function, they contain explicit discussions on the tensions between external and internal expectations of particle physics research, as in the passage below:

> EPP *(elementary particle physics)* is supported by our societies, their governments and funding agencies primarily because this prestigious research is an essential part of the culture of our nations or regions. Today, however, other probably equally important sciences exist and request funding. In addition, a number of applied sciences promise a quicker turn-round of the investments into products that can be sold on the world market. Thus, technology transfer (TT) is very attractive to funding agencies and governments. Therefore, in addition to providing knowledge, evidence of economic usefulness and technological relevance are also required from a science, such as EPP.
>
> (Åkesson et al., 2006: 162, *italics* added)

As shown, embedded in the current science-policy environment, the European particle physics community has noted the challenge to their cultural status from other research disciplines, especially those that swiftly deliver practical benefits.

Firstly, it is intriguing to see that the research community considers itself 'an essential part of the culture', focusing on communicating its cultural value in the strategic document. Secondly, however, the research community has sensed the importance of evidencing the economic and technological impact of particle physics research, to legitimise its research and successfully compete with applied research for funding. As we can see from the passage above, the need to provide wider benefits is still not an internal goal of the research community, but rather a situation they have to contend with. The way the European particle physics community interacts with the funding environment explains, to a certain extent, the exteriority of the importance of the technological relevance of particle physics research to the European particle physics community.

Nonetheless, arguing that particle physicists express their own interest and preference only because they have encountered discursive difficulty when attempting to justify their asymmetrical stance, would lose sight of the research community's active role in the negotiation between internal and external expectations. As is made clear in the 2006 Strategy briefing book, the key message the European particle physics community wishes to impart to policymakers and society in general is the value of curiosity-driven research, as the emphatic tone of this next passage illustrates:

> When communicating our activities to a wide audience, the focus should be on the basic research, it would be a mistake to market fundamental research for its technological and economic aspects. Firstly, because only a few of its spin-offs will have a real impact on our daily lives but, more importantly, because it would not do justice to its true motive: curiosity. It is human curiosity that drives fundamental physics: to understand the

> natural phenomena of our world, the structure of matter and forces, and ultimately the origin and evolution of the Universe.
>
> (Åkesson et al., 2006: 188)

I argue that the communicative strategy stated above echoes No. 3's final narrative layer (more discussions on p. 167), in which the 'honest answer' no longer manages external expectations but stresses the internal interests of the research community. In this clarification, the practical impact of particle physics on society is once more 'blamed' for misrepresenting the 'haecceity', or the essence of particle physics: it is never the 'true motive' of the research community, while curiosity-driven enquiry is. Therefore, I argue that, as such a representational strategy has been proposed in these strategic documents, the empiricist examples relating to technological and economic benefits from particle and high-energy physics research function as socially acceptable lexicons to legitimise curiosity-driven particle physics in contemporary science-policy culture. In other words, through the discursive performance of the wider importance of particle physics, the discussion about science-policy expectations, and determination of the research community's communicative strategy, we can all observe the hierarchy of interests that guides the European particle physics community's narrative in the 2006 Strategy briefing book.

The research community views the limited impact of particle physics on daily lives not as a situation in need of improvement, but as a reason to rationalise curiosity-driven research. This rhetorical practice, I argue, is 'boundary-work' (Gieryn, 1983), carried out by the research community to legitimise arbitrarily curiosity-driven research and eschew social responsibilities. Note that the final part of the passage above does not explain in any detail the unique contributions of particle physics to increasing general human understanding. Instead, prosaic terms such as *'natural phenomenon'* and '*the origin and evolution of the Universe*' (Åkesson et al., 2006: 188) are employed to support the legitimacy of particle and high-energy physics research. I argue that this discursive style reveals the subjectivity of the stance taken towards this research-community-wide communicative strategy.

Even though the discursive strategy of the European particle physics community that I have identified from document analysis shares a hierarchical pattern with No. 3's narrative arc, one could still argue that such a high-level political mobilisation for particle physics is not necessarily the intention of individual particle physicists. Therefore, in order to further investigate particle physicists' intentions when engaging with the general public, I prompted my Edinburgh particle physicist interviewees to discuss their public outreach and policy communication experiences in some depth: I present my findings in the next section.

5.4 Interpreting Public Engagement

When asked about their engagement activities, all my particle physicist interviewees presented themselves as fully comprehending the importance of public outreach or public engagement. This interactional tendency is close to No. 3's immediate management of his public image upon hearing the same question. However, as these particle physicists proceeded to describe what materials they had prepared for a wider audience, or how they had practised such communications, I have noticed that the alleged importance of public outreach relates more to themselves than the public. Firstly, the hierarchical narrative arc that I identified in No. 3's discourse reflects this characteristic. Secondly, during my fieldwork six particle physicist interviewees expressed a strong focus on disseminating their personal enthusiasm in public outreach. I followed this up, double-checking my interviewees' intentions, and as a result, thirteen out of the sixteen particle physicist interviewees revealed the strategic or subjective purpose of their participation in wider communication. In the analysis below, I illustrate how particle physicists at various career levels and of different generations share a common discursive pattern when accounting for the purpose of public outreach.

Number 2 retired particle physicist not only has over forty years of public outreach experience, he is the founder of the Edinburgh particle physics group's outreach team. When I interviewed him, No. 2 passionately described the various kinds of public outreach activities he had practised throughout his career, such as designing exhibition panels with interesting stories, organising entertaining outreach field trips, developing miniaturised experimental models, and engaging school kids in hands-on particle physics exercises. Hence, after these discussions, I asked No. 2 to explain why he and his community are interested in public outreach. His answer, as shown below, again interprets particle physicists' social responsibilities as bolstering the research community's epistemic value:

> It's nice to tell people what's going on by inviting them to come and hear a public lecture of some sort. So there is a certain element where public engagement is now seen as not just required, but necessary, in fact, socially necessary, because you have to get more people doing science; because there are big questions to answer.
>
> (Interview No. 2)

I argue that while No. 2 talks of 'inviting' people, indicating his friendly and open-minded attitude towards public engagement, the 'nice' part of reaching out to the public, as explained after the repetitive articulation of this social responsibility in the third sentence, still centres on scientific enquiry. That is to say, although No. 2 acknowledges that public engagement is now a responsibility of scientific researchers, he interprets this policy, which is expected by the funding agency *'to generate dialogue and trust between research and society'* (RCUK, n. d.-b), as a version that conforms to the epistemic interests of the particle physics community. Following this interpretation, No. 2 only vaguely describes the need to answer big questions as the motivation for research. I argue that this general account indicates No. 2's rhetorical management of his asymmetrical stance, which, as shown in section 5.1, is similar to the way No. 3 concluded each of his narrative layers. Given the contents and forms of No. 2's outreach practices, and his reasons for engaging with a wider audience, the 'dialogue' between particle physics and society anticipated by the impact agenda is unlikely to be two-way or critical: No. 2 only expects positive reactions or feedback from his audience.

There is a possibility that Nos. 2 and 3 particle physicists' strategic aims for public outreach are related to their seniority and experience. However, the discursive pattern they employ can also be observed in accounts by junior and mid-level particle physicists. For example, No. 4 junior particle physicist, who when I interviewed her was about to secure a tenured position following a Royal Society fellowship[42], explained her interest in public outreach with a discursive transition close to that employed by No. 2 particle physicist:

> A lot of people have this sort of idea. That is, science is really a mysterious and a very separate thing. I just simply don't believe that this is true. I think it's important to tell people that: 'Yeah, they can understand this'. You know *[laugh]*, you don't need to have done this at school *[pause]*. I also think, the general public, every taxpayer that is paying for our research, they have a right to know what it is that we're doing *[pause]*. And I think this country as a whole should be excited by what we are capable of doing. I think we saw, like Peter Higgs, you know, the discovery of the Higgs boson. Everybody really got behind this man, who made this prediction fifty years ago and was waiting for his Nobel Prize.
>
> (Interview No. 4, *italics* added)

We can observe here that No. 4 firstly expresses her empathy for the general public and deems them capable of understanding particle physics. Furthermore, she speaks of the general public's 'right to know', demonstrating her awareness of the social responsibilities that come with publicly-funded research. Nonetheless, No. 4 theorist then makes a discursive transition, shifting from defending the public's rights to requesting their intellectual obedience. In other words, I argue that No. 4's use of the normative verb 'should' demonstrates that her explanation for the importance of public outreach embodies the hierarchy of interests of the particle physics community that emphasises epistemic value. No. 4's double-layered account epitomises the tension between societal interest and the epistemic interest of the research community. In this sense, the first part of No. 4's answer

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[42] Number 4 particle physicist did not request anonymity and therefore this identifiable information can be presented here.

is her management of external expectations, which cushions the effect of expressing her hope for unconditional support or enthusiasm from society. Once more, this discursive order is similar to the communicative strategy I previously identified, in which external expectations are discussed prior to internal expectations. However, the way No. 4 discusses Peter Higgs and the Higgs boson, which lacks a convincing explanation of why such a discovery is intellectually important, once again reveals her subjective stance on the purpose of public outreach for particle physics.

Number 8 mid-level particle physicist also described the importance of public outreach for the particle physics community:

> I find it important. *[...]* I think you have to go out and explain to the general public what you are doing, not only because you are using their tax money, but also to *[hesitation]* make sure that they can follow what the boundaries of science are doing, and they have an understanding of why and how this is influencing their daily lives. *[...]* There has been *[pause]*, basically a counter movement, people are becoming very science sceptical. So the only way to counteract is to educate so that people can understand in laymen's terms what we are doing and why. So that's one of the important goals of outreach, because if you don't do that, eventually it may lead to: 'No, this is not supported by the general public'. Then you don't get funding anymore *[laugh out loud]*.
>
> (Interview No. 8, *italics* added)

Number 8's description conveys his concern about scepticism towards science rather than any interest in societal benefits. In No. 8 experimentalist's opinion, people's distrust is caused by a lack of understanding of science and its contribution to society. However, this opinion also implies a positive image of science in general, which is progressive and serviceable. No. 8 makes no subsequent attempt to empirically specify how and why particle physics has a positive influence on our daily lives; neither does he mention any of the reasons people might have for doubting science.

However, in a different part of the interview, No. 8, an instrumentalist specialising in developing particle detectors[43], declared that he had rarely seen opportunities for technology or knowledge transfer in his own projects. In other words, I argue that No. 8's description of the inherent good of science is not an empiricist but a contingent repertoire. Discursively, this general representation of science is rhetorical groundwork, establishing a base from which to argue the subjective purpose of outreach: counteracting scepticism. That is to say, No. 8 regards public outreach more as a strategy to secure support and resources than a social responsibility to taxpayers. As a result, I argue, No. 8's performance of the relationship between science and society remains at the level of the 'deficit model' and concentrates on the epistemic authority of science. No. 8 laughed out loud at the end of his justification, implying he sensed he had over-expressed his asymmetrical and strategic stance on public outreach. To clarify, analysis of an interviewee's laughter is not analysis of a mental state but rather of an element of social interaction within discourse (refer to sub-section 2.5.2: p. 80).

Based on my analysis, I argue that in response to my probing the majority of particle physicists I interviewed – at various career stages and of different generations – conveyed their strategic reasons for practising public outreach. This

[43] Number 8 particle physicist did not request anonymity and therefore this identifiable information can be presented here.

correlates with the European-community-wide strategic advice for future particle physics, an official response to policy expectations relating to the impact and social responsibility of research. In other words, the encouragement to the scientific community to practise public engagement can also be actively interpreted by the research community and transformed into a tool or space for the research community to mobilise support and resources. Even Professor Peter Higgs, the central character in public outreach for particle physics, the Higgs boson and CERN, was clear about the strategic importance of public outreach:

> After the LHC started up, I kept getting pushed into doing more *(public outreach)*, and I *[laugh and pause]*. Gradually over the years, I learned how to do it *[laugh]*. I think it is important, after all, they are the public who provide the money ultimately. I mean, if you don't have the public's backing, you may lose the politicians' backing *[laugh out loud]*.
>
> (Interview No. 13, *italics* added)

Professor Higgs, who was, as described, *'pushed into doing'* public outreach, embodies the strategic representation of particle physics. That is to say, Professor Higgs' fluent explanation of the wider contributions of particle physics research to society (more discussions in section 4.5: p. 146), as he acknowledges above, is more a learnt repertoire than the reflection of his personal research experience. However, I also argue that for a general audience, such a storyline endorsed by Professor Higgs—the father of the Higgs boson—is authoritative and trustworthy. One may argue that I take this part of Professor Higgs' discourse too seriously, but the several bursts of laughter that Professor Higgs made in the passage above suggest the tension between the representation he made earlier and the personal explanation he gives here. As Mulkay and Gilbert have stated (1984), humour or laughter is an interactional technique to mitigate a contrast between repertoires. Similar mitigation can also be observed in No. 8 particle physicist's account quoted in this section. Consequently, to study and understand descriptions of the impact of particle and high-energy physics we have to consider the (re)action and purpose of such discursive practices.

5.5 Interacting with the Hierarchy of Interests

So far, in the first and the second empirical chapters, I have argued that representations made by the particle physics community in interviews, outreach settings, and policy advisory documents, are embodiments of the research community's hierarchy of interests. That is to say, storylines about the value and importance of particle and high-energy physics, notwithstanding their socially-relevant style (Linear Model), can be perceived as a cover for particle physicists' emphasis on curiosity as the motivation for research. Consequently, the interests of the particle physics community are still in tension with contemporary science-policy expectations concerning the impact and social responsibility of research. Nonetheless, one may argue that an asymmetry exists in these two empirical chapters: only the actions and reactions of particle physicists in response to their social relations are studied, while external expectations are not. Such a unidirectional analysis may lose sight of dynamic interactions between the particle physics community and the policy agenda.

As a result, in the next and final empirical chapter of this thesis, I present the perspectives of the knowledge transfer and communication officers of European particle physics, the intermediaries of policy introduction and implementation in the research community. These findings result from the same interview and discourse analysis techniques. That is, I studied how these non-particle-physicist officers accounted for and practised the wider importance of particle and high-energy physics research. With this thread of empirical evidence, I discuss further how these officers – the embodiment of external policy expectations – act and react upon the particle physics community's hierarchy of interests. Furthermore, at the end of the last empirical chapter, I evaluate the tentative but ongoing effect of contemporary policy intervention on the long-standing epistemic authority of the curiosity-driven particle physics community.

Chapter 6

The Hierarchy of Interests as Priorities for Action

6.1 Chapter Introduction

The analytic approach of this chapter mainly mirrors that of the previous empirical chapters, but examines the object of study from the other side, showing how Knowledge Transfer (KT) practitioners at CERN interact with the internal culture of the European particle physics community. Having determined a hierarchy of interests from the interviews with Edinburgh particle physicists and the working documents of the European Strategy for Particle Physics (the Strategy), the focus of my analysis in this chapter centres on the interests expressed by these KT practitioners and their reflections on interactions with the interests of CERN. In section 6.2, I argue that, compared to the Edinburgh particle physicists I interviewed, a majority of the KT practitioners at CERN deployed a different discursive pattern to justify the value and importance of particle physics and high-energy physics (HEP) research. However, this different discursive pattern also reveals its interactions with the hierarchy of interests I identified in the previous two empirical chapters. Moreover, I argue that these KT practitioners, despite having their own interests to pursue, have learned and absorbed the culture of the hierarchy of interests at CERN.

Therefore, in order to study how the CERN KT practitioners evaluated the consequences of this hierarchy of interests for practising knowledge transfer for particle and HEP research, in section 6.3, I investigate the reflections of these KT practitioners on their experience at CERN. As a result, I have discovered in point 6.3.1 that a majority of the CERN interviewees and a high-level particle physicist on the CERN Council associate more difficulties than opportunities with the transfer of knowledge and technology from CERN to industry and society. I argue that this finding is worth noting since it interconnects with the characteristics of curiosity-driven scientific work that prioritise epistemic value. Furthermore, in point 6.3.2, I argue that despite employing repertoires to manage the representation of the particle physics community, the CERN KT practitioners expressed dissatisfaction with the limited interest shown by the internal research community in the wider impact and practical contributions of their research. In general, CERN KT wished for more interest and participation in knowledge transfer from the research community. Consequently, through the lens of the KT practitioners' discursive patterns and opinions, in this chapter I again question the imagery of the European particle physics community, which resembles the construction of the Linear Model (linear model of innovation) but does not necessarily represent its internal work culture.

6.2 Knowledge Transfer Practitioners' Ambivalence

As opposed to the particle physicists I interviewed, who tended to point to the important status of particle physics when I asked for their research motivations, the KT practitioners I interviewed at CERN did not tend to revere particle physics when accounting for their motivations[44]. Having asked these KT practitioners for

[44] I interviewed the CERN KT officers after interviewing the Edinburgh particle physicists.

further opinions on the value and importance of particle physics, I discovered that six out of the ten current and former CERN KT practitioners (or six out of eight KT practitioners who have no curiosity-driven physics research background) accounted for the significance of particle physics with a different repertoire from that used by particle physicists and the strategic documents. In the analysis below, however, I argue that this repertoire, in a different manner, still resonates with the hierarchy of interests of the European particle physics community.

As discussed in previous empirical chapters, particle physicists tend to articulate the wider impact of particle physics before fully revealing their curiosity-driven motivation for research. I have also argued that this discursive pattern is a management of external expectations. In this chapter I relate how KT practitioners at CERN generally acknowledge the value and importance of curiosity-driven particle physics research before expressing their personal concerns about the usefulness of science. Therefore, in this section, I analyse in detail the characteristics of this discursive pattern by focusing on the discourses of two KT practitioners, Nos. 8 and 9 CERN interviewees, out of the six CERN interviewees who gave similar accounts. In brief, although these KT practitioners structured the order of their justifications differently to the particle physicists, both groups tended to place their personal opinions, embodying their subjective interests, at the end of the discourse.

Therefore, I was aware of the discursive differences between these two interviewee groups from the data collection phase and was able to guide the KT interviewees to elaborate on what had been articulated by the particle physicist interviewees.

Nos. 8 and 9 CERN interviewees' responsibility in the KT group is to directly manage KT activities, such as those relating to the charge amplifier 'NINO' and the 'CERN-MEDICS' project to provide isotopes for medical research, so these two individuals have first-hand experience in the wider applications of CERN's research. In separate interviews, I asked them to explain the value and importance of particle and high-energy physics research. In response, both KT officers started their answers by noting the importance of curiosity-driven research:

> As a very well-known person has said: 'curiosity is human nature'. So there will always be the curiosity for more, and this justifies not only CERN but things like NASA, things like *[hesitation]*. So this is a human nature that we need to fulfil, we need to pursue in the understanding of the Universe.
>
> (CERN interview No. 8, *italics* added)

It can be observed from the above quotation that No. 8 CERN KT officer adopted a third-person perspective to assert the importance of curiosity, yet he did not specify the source of this saying[45]. Hence, I argue that such an account is a contingent repertoire rather than an empiricist repertoire, used by CERN No. 8 to express his support for curiosity-driven research. Furthermore, the way CERN No. 8 illustrated the importance of curiosity, which emphasises its commonality among humans, is similar to the discursive strategy of the particle physicists I interviewed (more discussions in section 4.1: p. 123, and sub-section 5.2.4: p. 167). Namely, such illustration constructs an immense appetite for knowledge, at CERN and

[45] This adage is similar to the first sentence of Aristotle's book series on Metaphysics: *'all men by nature desire to know'*, as translated from Latin. See: ROSS, W. D. 1953. *Aristotle's Metaphysics,* Oxford, UK, Clarendon Press. However, during the interview, CERN No. 8 could not remember the source, and I did not supply any further information.

throughout humanity. Nonetheless, as CERN No. 8 also mentioned NASA and could not, subsequently, conclude his justification for particle physics and HEP research, I argue this general account cannot specifically justify the significance of particle physics. We can observe that, having mentioned NASA, CERN No. 8 added prosaic statements to conclude his justification. Once again, I argue that these commonplace assertions are not able to explain in detail what the understanding of the Universe really is, why it is crucial to human beings, and how particle physicists can specifically address the issue.

Moreover, a discursive transition takes place after CERN No. 8's general claim. That is, CERN No. 8 started to express his personal opinion on the value and importance of particle physics, which contrasts sharply with the interests of the European particle physics community. This transition is similar to the discursive shift made by the particle physicists after they had presented general accounts. For instance, CERN No. 8's discursive transition is initiated by usage of the first-person subject in his answer:

> I tend to be a bit more practical, and I tend to believe and to see the practical advantages of the deep study of fundamental physics and particle physics, etc., etc., which are the collateral knowledge that comes out of it *[pause]*, such as the PET *(Positron Emission Tomography)*, the medical imaging, hadron therapy, detectors, all these side discoveries, and the World Wide Web, the technology that comes out of this huge lab.
>
> (CERN interview No. 8, *italics* added)

As quoted, CERN No. 8 did not use an unknown third person to convey his interest in the practical advantages of particle physics. I argue that this change in subject use implies that CERN No. 8 presents his personal stance as supporting the practical importance of particle physics. This presentation of stance clearly differs from that of the particle physicists I detailed in the previous empirical chapters, as they were by and large relatively uninterested in the practical applications of research (more discussions in section 4.5: p. 146). Furthermore, the examples CERN No. 8 provides, aside from the internet, have little relation to particle physics research per se but are closer to biomedical engineering; his own research background[46]. As a result, we can see that even with a set of practical examples similar to those mentioned by the particle physicists I interviewed, CERN No. 8, by using the first person as subject, creates a different kind of narrative to justify the value and importance of particle and high-energy physics.

CERN No. 8 rhetorically harmonises his stance with that of the particle physics community: he employs the terms 'collateral knowledge' and 'side discoveries' to imply the practical importance of particle physics and HEP. In other words, although CERN No. 8 did not explain to me the connections between these applications and curiosity-driven particle physics in detail, he asserted the existence of such a linkage through his use of language. In fact, throughout the entire interview, CERN No. 8 repeatedly used the word 'collateral' when referring to the practical advantages of particle and high-energy physics: these additional usages were '*collateral benefit*', '*collateral activity*', '*collateral way*' and '*collateral applications*' (CERN interview No. 8). Hence, I argue, even though CERN No. 8 was personally concerned about the applicability of science, he rhetorically manages this aspect, cushioning the tension within the discourse between his personal interest and the interests of the particle physics community. Moreover, I argue this

[46] The backgrounds of the CERN interviewees can be found in Appendix D (p. 253).

management indicates CERN No. 8's awareness of the dominance of curiosity-driven research in the workplace. After all, he describes particle physics as '*the deep study of fundamental physics'* (CERN interview No. 8), revealing his admiration of the curiosity-driven work culture at CERN.

My foregoing argument is supported by CERN No. 8's supplementary comment after he exemplified the practical advantages of particle physics research in the quotation above. That is, without any further prompting from me, he denied that technology could define the value or importance of particle physics and HEP research:

> This is not only the technology, okay? This is more on the top of the pyramid *[pause]*. But I tend to be practical. The practical know-how for us to discover our Universe is of great importance, fundamental importance, to society.
>
> (CERN interview No. 8, *italics* added)

In this quotation, CERN No. 8 provides no empirical grounds to support his denial but constructs the superior status of pure science by arbitrarily claiming *'This is more on the top of the pyramid'* (CERN interview No. 8). I argue that although CERN No. 8 does not explain in detail what he means by 'pyramid', the imagery of this word resonates with the hierarchy of interests of the particle physics community I identified in the previous chapters. However, after his vague description of the status of particle physics research, CERN No. 8 paused and swung back again to his personal concern about the practical advantages of research to society. The discursive pendulum between CERN No. 8's personal interest and the 'official' interest of the particle physics community illustrates the fact that anyone intending to practise knowledge transfer at CERN has to confront the research community's hierarchy of interests, which places considerable emphasis on the importance of curiosity.

I further argue that the mention of CERN No. 8's personal interest challenges the credibility of his first justification: the claim that curiosity is a common goal of all human beings and has to be pursued. At the end of the above quotation, CERN No. 8 employs the same rhetorical use of 'fundamental' as the particle physicist interviewees. However, CERN No. 8 has a different purpose: to describe the great importance of the 'practical know-how' behind curiosity-led scientific discoveries, rather than the curious motivation per se. Hence, it can be seen that the same rhetorical device can be deployed flexibly by different actors in support of their various stances. In other words, use of the word 'fundamental' cannot be taken by itself as evidence of a particular stance on the importance of particle and high-energy physics research. Rather, it is a clue to discovering the subjective stance that such a claim is intended to support.

I double-checked CERN No. 8's ambiguous assertion of his interest in particle physics by asking whether he had experienced a similar curiosity when studying biomedical engineering or working in the biomedical electronic engineering industry. In response, CERN No. 8 declared he had held no interest in particle physics prior to joining CERN. He employed the words '*virus*', '*bubble*' and '*contagious process*' (CERN interview No. 8) to describe his interactions with the CERN staff members interested in curiosity-driven particle physics research, presenting his interest in particle physics as an outcome of the socialisation process at CERN rather than his starting point. Therefore, it can be said that the interest in particle physics is exterior to No. 8 CERN KT practitioner. Nevertheless, from the rhetorical management between interests in the quotations above, we can observe that CERN No. 8 is unavoidably affected by the European particle physics community's hierarchy of interests.

In the next section, section 6.3, I examine in detail the influence of this hierarchy of interests not only on the rhetorical management of the KT interviewees but also on their knowledge transfer practices at CERN. Before moving to the next section, I compare the discursive pattern of CERN No. 8 with the discourse of No. 9 CERN interviewee in response to the same question about the value and importance of curiosity-driven physics research.

Despite differences in the personal features of CERN No. 9's vocabulary-use, her discursive pattern has a similar duality to that of CERN No. 8:

> I think it's important to know more about the world and the Universe, and so I would be in favour of doing fundamental research. And also, you don't know what can come out of fundamental research in the future. I mean *[pause]*. So to give you an example, of course, we found the Higgs boson particle here in 2012, and the world asked: 'Okay, we found the Higgs boson particle, but what benefit does it give to the world?' You know, apart from knowing that it exists, and the knowledge for the sake of the knowledge *[pause]*. I think it is important to have knowledge for the sake of knowledge, first of all, but I think that the benefits can come economically, socially and educational-wise, they may or may not come, if they do, they might come much later on.
>
> (CERN interview No. 9, *italics* added)

As shown, at the beginning of the quotation, CERN No. 9 expresses her support for curiosity-driven physics research by claiming the significance of pure understanding. I argue that this notion is close to CERN No. 8's discursive strategy:

praising curiosity-driven research first. However, as CERN No. 9 proceeds to expand her explanation, without my probing but after a pause, she has problems evaluating the outcomes of curiosity-driven physics research. Consequently, after her roundabout way of articulating the uncertain benefit of fundamental research in general, CERN No. 9 returns to her starting point and once more asserts the importance of pure understanding without providing a robust explanation. Furthermore, CERN No. 9 uses '*first of all*' at the end of her second assertion: *'It is important to have knowledge for the sake of knowledge'* (CERN interview No. 9). I argue that this phrase indicates her insistence on prioritising curiosity-driven research, and such prioritisation resonates with the hierarchy of interests of the European particle physics community. Nevertheless, following this rhetorical insistence, CERN No. 9 still could not specify whether or not there are, or will be, benefits from particle physics and HEP research. In the end, she concludes her vindication by vaguely hinting at the possibility of obtaining wider benefits in the future. I argue that this anticipatory rhetoric is close to one of the methods particle physicists employed to manage the rhetorical dilemma in their asymmetrical accounts of the wider importance of particle physics research (read more in section 4.4: p. 140).

The key difference between CERN Nos. 8 and 9's discourses is that CERN No. 9 employs a different subject voice to begin sentences justifying the various interests in scientific research. Namely, unlike CERN No. 8, CERN No. 9 employs the first-person subject to show her support for fundamental and particle physics research but uses a third-person subject – 'the world' – to question the wider contribution of curiosity-driven physics research. This difference does not necessarily indicate that CERN No. 9 has a different interest to CERN No. 8; in the part of the interview about her personal background, CERN No. 9 related more about her personal interest in applied research:

> So I think I like all sciences, and I also find physics interesting, but my preferred science is probably biochemistry that I did my PhD in. I guess *[hesitation]*, yeah, I was always interested in seeing how you can apply technologies that are created in the laboratory to the world, and finding applications of some of the inventions.
>
> (CERN interview No. 9, *italics* added)

Comparing this with the previous quotation, we can observe that CERN No. 9 does not always refer to her personal interest in technological applications. Since the latest quotation was CERN No. 9's reply to a question about her personal research background, while the previous one was her response to a general question about the importance of particle physics, I argue that her usage of 'the world' is a rhetorical tool to describe her personal interest in the usefulness of science as a collective interest shared by many, rather than her own preference. Otherwise, CERN No. 9's presented support for 'fundamental research' would contradict her own preference. This rhetorical management is in sharp contrast to her performance when defending curiosity-driven research: for instance, when she states: '*I definitely believe in doing fundamental research, and in letting people follow their questions of curiosity for the sake of advancing knowledge for the human race*' (CERN interview No. 9). In the discursive context of the latest quote she is clearly discoursing on behalf of herself. As a result, although her use of subject voice differs from that of CERN No. 8, CERN No. 9 also adapts, at least discursively, to the hierarchy of interest of the European particle physics community. Even when describing her educational background, CERN No. 9 displayed her general affinity for science and physics before conveying her specific preferences for biochemistry and applied research.

The hierarchical discursive layers of Nos. 8 and 9 CERN interviewees epitomise the tension between the majority of the CERN KT practitioners' interest in the applicability of science, and the emphasis placed by the European particle physics community on curiosity-driven enquiry. In this section, we have seen how such tension is mitigated by rhetorically incorporating two interests into one justification. Nevertheless, I argue that the tension between interests in the interviews with CERN KT officers suggests that knowledge transfer practice in the particle physics research institution is likely to be strained by the scientific culture of the curiosity-driven research community. Hence, in order to examine how the diverse interests in this workplace are managed and adjusted, in the next section, I study CERN KT officers' reflections on their interactions with the researchers[47] at CERN in promoting the impact and social responsibility of research.

6.3 Accelerating Particles, Accelerating Impact?

I argue that rhetorically bringing different interests into harmony has made particle and high-energy physics research appear able to satisfy a range of expectations. That is, curiosity-driven particle physics research is presented as not

[47] There are not only particle physicists but other disciplinary scientists and engineers working at CERN to run the high-energy physics experiments. Therefore, the KT officers at CERN also interact with other experts to facilitate knowledge transfer. In this thesis, I take these interactions all as encounters with the work culture of the particle physics community.

only advancing the understanding function of science but also facilitating technological development, economic growth and societal benefits. Moreover, the other four CERN KT practitioners, who accounted for the significance of particle physics with less or unapparent mention of their personal interests, still asserted a close relationship between particle physics and its wider contribution to society. Consequently, these discourses have constructed an almost miraculous influence on society from particle physics. However, the Linear-Model-like repertoires deployed by both Edinburgh particle physicists and CERN KT practitioners do not discuss the degree of effort required to link investment in pure scientific enquiry with the generation of practical usages and benefits. Even after my probing and prompting in interviews, none of the particle physicist interviewees was able to address this issue in detail. Therefore, it is necessary to understand more about the experiences of CERN KT officers, who are at the forefront of generating wider impacts for particle physics and HEP research. To clarify, I also treat these related experiences as discourse rather than fact, and analyse how these experiences are described and why they are explained in the way they are.

In this section, I compare the CERN KT interviewees' assertions or presumptions relating to the practical importance of particle physics research with their accounts of knowledge transfer practices and experiences at CERN. As a result, I have found two recurring discursive styles in these officers' opinions relating to their knowledge transfer practices and experiences at CERN:

1. *The tendency to relate difficulties*

2. *The tendency to attribute these difficulties to the 'un-interest' they encounter.*

The first type of discourse describes the wider influence of particle physics with less optimism than the discourse analysed in section 6.1, while the second does not regard the diverse interests in the workplace at CERN as harmonious enough to engender successful knowledge transfer. That is to say, both discourses suggest that the positive, even heroic accounts of the significance of particle physics are not based on the subjective experiences of the CERN KT interviewees. Therefore, I argue that my findings in this section once again demonstrate the rhetorical function of the accounts presented in section 6.1.

6.3.1 Accounting for Difficulties

When I asked the CERN KT practitioners to evaluate the outcome of their knowledge transfer efforts for particle physics and HEP research, they tended to relate the difficulties they encountered when attempting to realise a wider impact at CERN. In other words, these reflections differ from the Linear-Model-like repertoires about the practical contributions of particle physics research in section 6.1. In total, eight out of ten of the current or former CERN KT practitioners reflected on the many challenges and limitations to transferring particle physics and HEP research knowledge and technology. In the following passages, I focus on analysing the discourses of Nos. 1, 7 and 9 CERN interviewees, a group leader[48], and a senior and junior KT officer. Notwithstanding their dissimilar positions and expertise (electronic engineering, computer science and biochemistry), these

[48] No. 1 CERN interviewee did not request anonymity and therefore this identifiable information can be presented here.

three interviewees all noted that the technologies and innovations developed at CERN serve very specific purposes. Thus, these inventions often provide little prospect of knowledge and technology transfer to industry and commerce.

As I found in the Strategy working documents (Table 1, p. 110), the cutting-edge characteristics of technologies and innovations developed for particle and high-energy physics research are often emphasised as a specificity of the impact of particle physics. For instance, the HEP facilities are often praised as very 'big', 'new' or 'advanced' (Åkesson et al., 2006). Nonetheless, I have found that these traits are regarded by my KT interviewees as key obstacles to successfully transferring knowledge and technology from CERN to society, as can be observed in the interview excerpts below:

> If we try to do technology-push with our technologies *[hesitation]*, it would rarely work. If we go out and say to the industry: 'Hey, that's the solution to my problem, do you happen to have the same problem so that I can sell you my solution?' The answer is very often: 'No'. Obviously, because they don't have a 27 kilometres long accelerator. *[...]* One of the inventions that one of our scientists did was a way to measure very low temperatures over a very long distance: 27 kilometres. This is really what is clever, okay? Now *[pause]*, if you go outside, and you say 'Hey, do you need something which can measure a temperature at 1.9 K over 27 kilometres or over 20 to 50 kilometres?' Well, it's difficult to find applications, you see? Not many people have this need, in fact *[hesitation]*, probably nobody has this need.
>
> (CERN interview No. 1, *italics* added)

> There is a lot of software being developed at CERN *[hesitation]*, it is not always obvious that it can be applied *[pause]*. I would say, most of the software that is produced here is quite specialised, or it is produced obviously with the idea in mind to serve the needs of CERN,

> which are basically why the people are employed here. This is the first priority: to serve the needs of CERN, which means that they might not necessarily produce a generic piece of software that can be used everywhere. *[...]* There is a flip side of that *[hesitation]*. Because of the nature of the requirements, and because the LHC or the other CERN experiments are very specific, we require a lot of specific developments that are really not *[pause]*, you know, some of them, many of them cannot be used widely in industry *[hesitation]*, I would say.
>
> (CERN interview No. 7, *italics* added)

> So, of course, it's quite interesting that we produce this nice high-tech equipment, for example, ultra-high vacuum. But then *[hesitation]* when you try to, or when you talk about this thing to, say, companies, and they will say: 'Wow, that's really impressive that you did that, but we don't need anything that advanced, and we are not going to pay more money for something exceeding what we need.' You know? 'If we only need a vacuum 10^{-9}, and your thing is 10^{-15}, well, that's great and impressive, but we are not going to buy it because it's more than what we need'. So I have found that's quite a barrier here when you are trying to talk to companies, you know? In fact *[pause]*, it's been easier to find the applications of the 'little less high-tech' technologies *[laughs]*. Indeed, the 'really high-tech thing' *[laugh]*, I have to find it *(the application)* myself.
>
> (CERN interview No. 9, *italics* added)

The quotations include discussions of the engineering, information and medical technologies that are part of research activities at CERN; these are the impact categories most frequently mentioned in the public outreach and policy advice repertoires, exemplified by the transistor, the World Wide Web (WWW) and proton therapy or the PET scanner. Although these KT practitioners firstly use positive or neutral rhetoric in describing the know-how and technologies relating to particle physics and HEP research—*'That is really what is clever'* (CERN interview No. 1), *'quite specialised'* (CERN interview No. 7), *'great and impressive'* and *'really high-tech things'* (CERN interview No. 9)—Their opinions or narrated experiences all suggest that the outcomes of curiosity-driven physics enquiry are seldom close to market needs. They describe these technologies as either having doubtful impact or requiring substantial further adjustment and development, beyond the interests of either the research community or industry, as well as the individual skills of these KT practitioners[49]. In other words, the concept of one-way 'knowledge transfer' or a 'technology push' to realise the applications of particle physics research is presented as particularly challenging.

One may argue that the cases of successful knowledge transfer reported by *CERN Courier* or the CERN KT annual report[50] refute my aforementioned findings and arguments. However, whether these reports reflect reality was also questioned by the CERN KT officers when asked to evaluate their KT practices. For example, CERN No. 5 noted that these success stories are rare cases that *'don't happen every day [...] and thus can't be the standard'* (CERN interview No. 5, bracket added), while CERN No. 3 expressed his concern that CERN KT were '*struggling'* to find *'impressive successful stories*' (CERN interview No. 3). Moreover, CERN No. 9 told me that one of the widely reported KT cases at the time I interviewed her – a solar panel technology – had been less than successful: the spin-off company

[49] I do not discuss the possible connection between this barrier to impact and the judgement of industry about commercial needs, as I do not regard the impact of particle and high-energy physics research as the responsibility of industry unless this is encouraged by the public sector.

[50] Open access to these two documents can be found at: https://cerncourier.com/cern-courier-digital-edition/, and https://kt.cern/about-us/annual-report.

created by CERN went swiftly bankrupt due to insufficient market competitiveness (CERN interview No. 9). In other words, due to the rarity of possible uses and the cost of transferring CERN knowledge and technology to society, justifying the cost-effectiveness of investing in curiosity-driven particle and high-energy physics research is problematic. However, aside from describing difficulties, these CERN KT interviewees did not reflect further on the economic aspect of curiosity-driven research.

I am in no way implying that these reflections on the difficulties of knowledge transfer are truer than the Linear-Model-like repertoires analysed in section 6.1. After all, the difficulties described in the interviews are also discursive constructions by the CERN KT practitioners. Nonetheless, I argue that it is significant that the accounts of restricted KT opportunities at CERN also reflect the epistemic interest of the European particle physics community more than its interest in wider impacts and practical benefits. That is to say, the KT difficulties described are by-products of the characteristics of curiosity-driven scientific work. As a result, I believe we need a deeper understanding of interactions between KT practices and the internal work culture at CERN and in the European particle physics community in general.

Since the majority of CERN KT officers are not particle physicists, questions may be raised over whether their accounts of difficulties do represent the work culture of the European particle physics community. However, in one of my two interviews with high-level particle physicists at CERN, CERN No. 12, I also detected a lack of interest or participation in the knowledge transfer of particle physics and HEP research. For instance, I firstly asked CERN No. 12, Chair of the CERN Council[51], the reason for a strategic emphasis on knowledge transfer in Europe, to which he replied that knowledge transfer *'is a matter of principle by all moral standards'* (CERN interview No. 12). I argue that this emphasis of moral standards is an attempt to justify the knowledge transfer policy without specifying any rationale. Nevertheless, because of his response to my further probing and prompting, analysed in the passages below, I also argue that such an account is simply an officially sanctioned representation of the European particle physics community.

To understand more about his personal opinion after this general claim, I then asked CERN No. 12 if he has carried out any knowledge transfer in his research. After a long laugh, CERN No. 12 resumed: *'Okay, so there is a difference between seeing things and having worked on things myself'* (CERN interview No. 12). This opening, and its amused introduction, indicates that his previous statement does not relate to his personal experience:

> This *(low-frequency detection technique for cosmic-ray observation)* is exactly what I need for my research, but I could also see tons of applications *[tone rising]*. *[Pause]* I have to admit that I haven't been able to engage with industries so far. The main reason for that is *[hesitation]*, all the industries I talked to expect me to do all the investment. *[...]* The thing is that, I don't have the money to invest, that's why I want to share this with the industry, and so they also pay part of the investment, but they are just not willing to. So that's a pity.
>
> (CERN interview No. 12, *italics* added)

[51] No. 12 CERN interviewee did not request anonymity and therefore this identifiable information can be presented here.

I believe the Chair of the CERN Council was aware of the discrepancy between the officially sanctioned imagery of particle physics research and his personal experience, as he then tried to mitigate this rhetorically, insisting it was industry that had no interest in developing the potential impacts of his research, not him. Despite announcing *'I could also see tons of applications'* (CERN interview No. 12), CERN No. 12 specifies none. Also, I argue that CERN No. 12's description of industry concern about investment implies that these applications are not yet ready and need substantial development. That is to say, the Chair of the CERN Council's anticipatory account unavoidably contains the difficulty of knowledge transfer from particle and high-energy physics research, which is not necessarily industry's responsibility. CERN No. 12's feeling of helplessness in terms of funding, presented at the end of his justification, is also questionable as he could consult CERN KT for assistance or advice.

Moreover, I argue that the discursive pattern CERN No. 12 employs is similar to the discursive transition between repertoires about the wider importance of particle physics used by the Edinburgh particle physicist interviewees (more discussions in section 4.5: p. 146, section 5.2: p. 157, and section 5.4: p. 178). That is, these discourses often begin with a general account that manages external expectations with empiricist claims, which are different from the internal, subjective interests rhetorically and emotionally elaborated later in the discourse. In addition, either with or without my probing and prompting, if the subsequent justifications of the particle physicist interviewees are personal, they are often accompanied with further rhetorical management, such as anticipatory rhetoric, repetitive rhetoric and laughter, to mitigate the discrepancy between repertoires.

To clarify, I have no intention of extrapolating the European particle physics community's general view of knowledge transfer from CERN No. 12's discourse; instead, I checked if the hierarchy of interests I identified in the discourses of Edinburgh particle physicist interviewees is echoed by European particle physicists. Although I only have CERN No. 12's interview[52], given he is the current Chair of the CERN Council, which represents the majority of European particle physicists at CERN, his discursive pattern is worth consideration. Hence, I argue that practices relating to knowledge transfer, wider impact and the social responsibility of particle physics and HEP research must take into account the unique occupational culture embodied by the discourse of my particle physicist interviewees, who believe the practical applications of science can easily be advanced by the generation of knowledge: a problematic concept that the dynamic practice of 'knowledge exchange' aims to address (more discussions in section 1.3: p. 38).

In the next point, the final part of my empirical analysis, I address the colliding and conflicting work cultures of knowledge transfer and basic research at CERN, as reflected on by the CERN KT officers. In this part, my focus is not on transitions between repertoires or the juxtaposition of storylines; instead, I focus on the CERN KT officers' discursive tendency to attribute the difficulty of knowledge transfer at CERN to the 'un-interest' they encounter in the workplace. Although the epistemological ground of this thesis regards speech as construction rather than fact, I argue that this discursive tendency echoes the European particle physics

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[52] As mentioned in Chapter 3 (from p. 89 on), the other CERN high-level particle physicist, No. 13 CERN interviewee, could only spare five minutes for her interview, making it difficult to explore her personal opinion.

community's hierarchy of interests I identified earlier. Consequently, it is important to explore the influence of these hierarchical interests on realising the wider contributions of particle and high-energy physics research to society.

6.3.2 Attributing Difficulties to the 'Un-interest' of Researchers

As well as articulating the difficulties of transferring knowledge and technology from CERN to industry and society, another repetitive theme appears in the discourses of CERN KT interviewees. When I asked the KT officers about the particle physics community's opinions of, and reactions to, knowledge transfer, the way they responded was different to the way they accounted for the value and importance of particle physics. That is to say, rather than rhetorically incorporating the community's curiosity-driven research motivation into their interest in the usefulness of research, half of the CERN KT interviewees (five out of ten, or out of eight KT practitioners who have no curiosity-driven physics research background) separated the community's own interests from institutional interest in knowledge transfer. This does not mean that one part of the interview excerpts analysed in this chapter is more correct than the other. Conversely, I argue that both discourses stem from the CERN KT practitioners' interactions with the hierarchy of interests: while the discourse analysed in section 6.1 complies with the research community's epistemic interest, the one I address in the following passages is separated from such concerns. In other words, both are 'boundary-works' (Gieryn, 1983) conducted by the CERN KT officers in different discursive situations: the former accounts for the importance of particle physics research; the latter explains the difficulty of realising the wider importance of particle physics research.

Moreover, I have found that interview questions about how knowledge transfer is perceived and implemented at CERN have an interactional function close to my usage of technical terms and concepts when asking particle physicists the current status and progress of particle physics (more discussions in section 4.3: p. 133). I argue that this is because my queries in this part of the interviews relate to mundane practices, thus both particle physicists and the CERN KT practitioners did not sense the need to adhere to repertoires that represented the research community as 'politically-correct'. From No. 1 CERN interviewee, the group leader, through CERN Nos. 3 and 5, two mid-level managers, to CERN Nos. 8 and 9 KT officers, half of my CERN KT interviewees actively acknowledged to me during or after interview that they found our discussions about their everyday practices the most interesting and relevant to their roles. Hence, although we must still be aware of the CERN KT practitioners' constructions in this part of the discussion, I argue that these discourses, to a certain degree, describe the conflicting work cultures between KT officers and researchers.

The key theme in these discussions about mundane knowledge transfer practices at CERN is the tension between an interest in knowledge transfer and the epistemic interests of the internal research community. Half the CERN KT interviewees have experienced more strain between their interest and that of the research community than enthusiastic cooperation. For example, in the interview excerpts below, we can see that three KT practitioners, a group leader, a section leader and an officer, all mention the research community's ambivalence towards knowledge transfer:

So today, at CERN, we say this is important *[hesitation]*, but people are not obliged to do it. So it changes very much. Some people are *(doing KT)* because they have a personal interest in their work being applied to other places *[pause]*. And there are some people that are happy to do what they do for the physics, and they are not interested in looking for other things very much. So can we change that? We have tried very hard *[pause]*. This is one of the things that I started when I took the job as a group leader. I tried to make an analysis of this situation, and I felt that *[hesitation]*, we, as a group, were a little bit isolated from the organisation; we were not known by enough people *[sic.]*. *[Pause]* I then massively started the internal campaign, in order to be known to more people and to contact as many people as possible. I try to say to them: 'Hey, you know, practical application is important.'

(CERN interview No. 1, *italics* added)

That's exactly one of the major challenges we have in our work. In a fundamental research lab like CERN, the first and primary objective of the scientists and researchers is the scientific mission *[hesitation]*. Knowledge transfer and finding applications for that is much lower on their priorities. *[...]* It is certainly not part of their job description, so they will definitely not see that 'Oh, I have to realise this or that' *[pause].* Their job is really to get the science done and achieve the scientific objectives.

(CERN interview No. 3, *italics* added)

I think one challenge that we face *[hesitation]*, and all colleagues are facing *[hesitation]*, is that we are in a high-energy physics lab, and our research is concentrated on high-energy physics and the engineering that supports high-energy physics. The more successful knowledge transfer becomes, the more pressure will be on our colleagues to participate, to give us their time and expertise because we rely on them *[pause]*. That is not always easy *[pause]*. So some people would do it voluntarily, while some people would never do it *[pause]*. I think one of the challenges of the group is to

> mobilise more people, to infuse the idea that knowledge transfer is good for them.
>
> (CERN interview No. 7, *italics* added)

I argue that all the above quotations depict the hierarchy of workplace interests at CERN. To clarify, this recurring image was not prompted by my interview questions (Appendix B: p. 249) but from these interviewees' voluntary responses to a neutral question about the research community's reaction to knowledge transfer. Therefore, the hierarchy of interests that I identified in the particle physicist interviews as well as the strategic documents of the European particle physics community has been experienced by half the CERN KT interviewees. In other words, this hierarchy of interests not only appears in discourse but permeates the internal work culture of CERN, the key research institution for European particle physics.

Despite the fact this account of the research community's 'un-interest' in knowledge transfer counters the Linear-Model-like repertoires most CERN KT interviewees made in their account of the importance of particle physics research (more discussions in section 6.2: p. 190), no obvious rhetorical management appears in the above quotations to mitigate the discrepancy between accounts. As a result, I argue that the lack of interest in practical applications at CERN, as related by these interviewees, is not a rhetoric that leads to rhetorical dilemmas or logical fallacies in need of management. After all, CERN No. 1, the group leader of CERN KT, voluntarily pointed out in the first quotation that asserting the importance of knowledge transfer does not necessarily guarantee the actual practice of knowledge transfer within the workplace. I thus further argue that in order to look beyond portrayals of the European particle physics community in regard to knowledge transfer policies, it is important to understand more about internal negotiations of the value and importance of knowledge transfer at CERN through discourse analysis.

We can observe that CERN No. 1 describes CERN KT as 'isolated', CERN No. 3 discusses how the mission priorities at CERN are obviously not centred on knowledge transfer and CERN No. 7 mentions his concern about trade-offs his colleagues have to consider when practising knowledge transfer. All these accounts suggest that knowledge transfer is not as inherent to particle physics and HEP research as the Linear-Model-like repertoires allege. Furthermore, these accounts differ from the way the particle physics community is represented in public outreach and policy advice repertoires (more disccusions in chapter 5, from p. 155 on), in which the wider impact and knowledge transfer of particle physics are mentioned earlier than its basis in curiosity-driven enquiry, implying the particle physics community attaches importance to the wider benefits of research. This importance, however, is not apparent when KT officers describe the internal work culture at CERN, in which the importance and urgency of scientific goals and activities overshadow knowledge transfer. Consequently, I argue that the key task of the CERN KT officers is not only to reach out to industry and society but to negotiate the importance and urgency of knowledge transfer with the hierarchy of interests of the European particle physics community.

My argument is supported by the organisation of CERN KT: the importance of internal communication can be observed in the role descriptions by CERN Nos. 2 and 6, and, as CERN No. 1 notes, CERN KT has been impelled to react to the research community's hierarchy of interests and detachment from knowledge transfer with internal campaigns promoting knowledge transfer. Therefore, under the leadership of CERN No. 1, No. 2 CERN KT officer, as full-time communicator for the KT group (not the general science communicator for CERN), focuses on showcasing successful knowledge transfer stories within the research community and developing communicative strategies for other KT officers; while CERN No. 6 is the entrepreneurship officer, responsible for fostering interest in knowledge transfer at CERN through informal after-work gatherings and charity hackathons[53]. During my fieldwork at CERN I observed many flyers and posters advertising numerous knowledge transfer workshops—rivalling the number of scientific workshops—at CERN or nearby, though as CERN KT did not invite me to any of these events, I have no knowledge of the research community's participation rates[54].

While external communication with industry, commerce and society is a crucial task for the CERN KT officers, it was the insufficient internal interest in knowledge transfer and the wider impact of research that most troubled the CERN KT practitioners I interviewed. The discourses from particle physicist interviewees and strategic documents analysed in this thesis make it clear the European particle physics community is resolute that its research is not motivated by applied goals, and the belief that wider and practical impacts will automatically materialise from curiosity-driven physics research is widespread. Nonetheless, the KT officers I interviewed repeatedly referred to the limited internal interest in knowledge

[53] Neither No. 2 nor No. 6 CERN interviewees requested anonymity and therefore this identifiable information can be presented here.

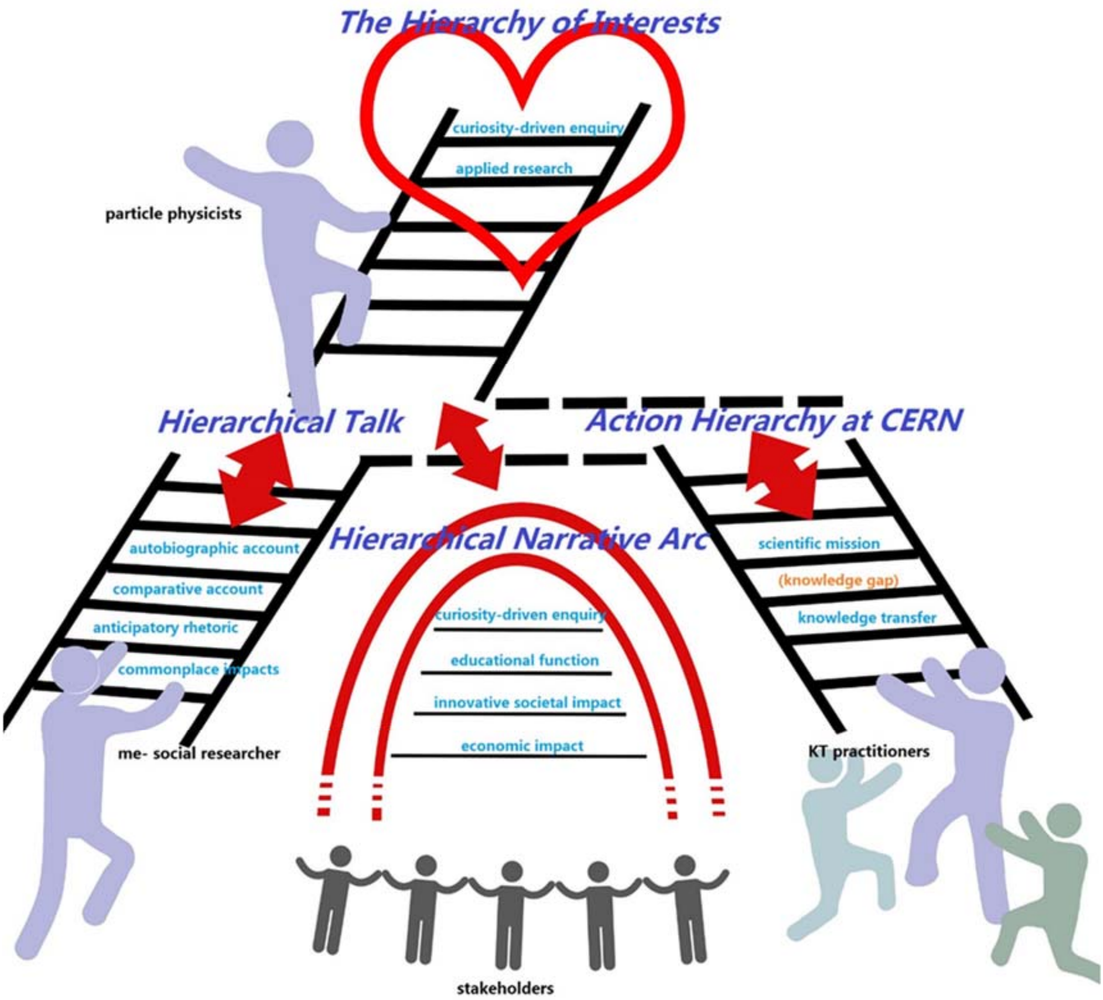
[54] CERN No. 6 mentioned in interview that the participation rate of after-work gatherings is increasing but still depends on the topic of the meeting.

transfer at CERN, and expressed their hopes of greater participation in knowledge transfer by the research community. As daunting as the challenge may appear, it is obvious that CERN KT can do more to improve the work culture within CERN than change the external environment of industry and commerce.

As a result, combining the arguments put forward in this section, which are not guided by EIDA, I argue that external expectations from the UK and European science policy community about the wider impact and social responsibility of particle physics research are repeatedly affected by the particle physics community's hierarchy of interests. This implication does not mean there have been no successful knowledge transfers by CERN or the European particle physics community. Nevertheless, from the articulation of difficulties encountered by CERN KT practitioners, their concerns about the research community's limited interest in the applied purposes of research, and the role descriptions provided by a number of KT officers, we can determine that the curiosity-driven motivations of the European particle physics community has made implementation of knowledge transfer and a wider impact for particle physics and HEP research less positive than the constructed imagery of the Linear Model depicts.

Furthermore, I argue that the multiple facets of the hierarchy of interests embodied by the members of the European particle physics community have been exhibited in my three empirical chapters. These are, firstly, the contrast between particle physicists' interest in curiosity-driven enquiry and their relative lack of interest in the applied uses of research, which structured the way particle physicists represented themselves and the research community to me in interview; secondly, the hierarchy of interests that emphasises scientific impact over the economic and societal effects of particle physics and HEP research, epitomised by the narrative arc prepared for public outreach and policy communications; and thirdly, the action hierarchy at CERN as experienced by the KT practitioners, which is interdependent with the hierarchy of interests of the research community (the interwovenness or co-production of these three facets of the hierarchy of interests is illustrated in Figure 2 below). I argue that the combined explanatory validity of these empirical chapters not only serves the purpose of methodological triangulation but has provided a theoretical insight by revealing the interplay between discursive practice and action taken. That is to say, talk is not merely talk but the embodiment of actors' motivations and the catalyst of actions that co-produce the material world with Nature.

Figure 2. The Hierarchy of Interests in Discourse



In the next and concluding chapter I will discuss how my findings in this thesis can contribute to SPS literature, particularly in studying the social relations of science and assessment policy. Moreover, I will provide advice for the science-policy community and reflect on the limitations and future prospects of my research approach.

Chapter 7 Conclusion

Colliding Particles, Colliding Cultures of Research

7.1 My Research Motivation

Setting the expense of high-energy physics (HEP) aside, the discovery of the Higgs boson and other particle physics investigations are indeed among the most fascinating human achievements, particularly in terms of the scale of experimental apparatus used, the numbers of international scientists and experts involved, and the educational possibilities (refer to section 1.1: p. 27). However, with regard to social responsibility, a policy trend that is increasingly penetrating contemporary governance, I argue that this publicly-funded research community will inevitably have to take more than its epistemic interests into consideration. While New Public Management (NPM) policy agendas since the eighties have placed an emphasis on efficiency and the provision of evidence of this, and have inspired the Science Policy Studies (SPS) community to empirically evaluate the outcomes, performances and returns of basic physics research (refer to section 2.3: p. 63), this has resulted in a gap between research evaluation or assessment policies and concern about the purposes of research. As a result, the objective of this thesis has been to return discussion about research motivations to the SPS, scientific and science policy communities in an age when the wider impacts and societal contribution of research are prioritised.

To date, there has been no systematic consideration of either the impact of the social responsibility policy on the curiosity-driven research community or its reaction to this agenda. My thesis was therefore designed to address this gap in the literature by providing, through the study of discursive patterns, an understanding of the attitudes and culture of the European particle and high-energy physics community in response to trends within science policy. I have proposed and tested a methodological framework of discourse analysis – ethnomethodologically-inspired discourse analysis (EIDA) – which I believe the science policy community could deploy for the empirical study of particle physics and other curiosity-driven scientific communities' discursive interactions with the pragmatic policies relating to impact and social responsibility. Despite the fact that constructivist discourse analysis does not analyse objective facts through discourse, and therefore we cannot study the actual effect of policy agendas on curiosity-driven research, it is appropriate for comprehending the relatively stable social realities of attitudes, categories, representations and rules (refer to section 2.5: p. 76).

7.2 The Importance of Curiosity and Its Challenge to Science Policy

Many science policy studies have been conducted from a constructivist perspective to investigate the social and historical shaping of the category or territory of curiosity-driven research, also known as 'basic' or 'fundamental' research (refer to section 2.2: p. 56). Nonetheless, aside from arguing that 'basic research' is one of the foundations of the Linear Model (linear model of innovation) (Edgerton, 2004: 1–36, Godin, 2006: 639), or the 'boundary-works' and 'political symbol' of the science policy and scientific communities (Calvert, 2006: 199, Pielke Jr, 2012: 339), I suggest there is as yet insufficient research examining the cultural influence of the label 'basic research' and other social constructions on the everyday advocacy of a research community driven by epistemic interests, such as particle and high-energy physics. That is to say, STS and SPS studies rarely examine the influence of policy expectations and requirements on scientists. I argue that as scientists are the key actors generating evidence and arguments in response to societal expectations and the governance of science, it is crucial we gain a greater understanding of this aspect.

The issue of why curiosity-driven physics research is worthy of investment has never been resolved in policy and society. This is not to imply that attempts have not been made; various approaches and arguments have been proposed since the eighties within SPS literature, alongside claims that the value of pure research or free enquiry is justifiable in certain ways, such as bibliometrics, qualitative interviews, ex-post impact assessment and evaluation of scientific facilities' productivity (refer to section 2.3: p. 63). Despite the fact that it is still difficult to pragmatically evaluate the outcomes and returns of curiosity-led physics research, these approaches and arguments accept a general premise: that the accumulation of knowledge not yet targeted to a particular context of use is valuable in its own right. This presumption not only prevails in the SPS community but is also part of the culture of curiosity-driven particle physics. In this thesis, I have discovered that the core of particle physicists' and CERN knowledge transfer officers' justifications of the value and importance of particle physics remains focused on the significance of 'curiosity' rather than on the practical applications of research expected by current UK and European science policy agendas.

This focus of justification, however, is not easily identified in the discourse I have studied, as both its style and content justify external expectations prior to expressing the epistemic interest of the particle physics community. Through studying the patterned characteristics of the justification of the value and importance of particle and high-energy physics research, I argue that articulating the wider benefits of particle physics research early in a narrative arc is a strategy for legitimising, in a wider context, the research community's epistemic interest (refer to section 4.5: p. 146, section 5.2: p. 157, and section 5.3: p. 172). In other words, the narrative hierarchy used by the European particle physics community in public outreach and policy advice still embodies the internal values and priorities of the research community, which are in tension with pragmatic science policy agendas in the UK and Europe. Consequently, although the hierarchical narrative arc covers both the expectations from and on the particle physics community, and both the tangible and intangible influences of particle physics research, I argue that this hierarchy is still instructed by the research community's predominant interest in pure research. Therefore, harmonic interactions between the European particle physics community and the science policy community remain representational or symbolic, which is an aspect that contemporary SPS literature and the science policy community have neglected.

The discursive management by the particle physics community is not necessarily conscious or intentional but is embodied in the empirical findings of this thesis in two ways: 1) the narrative order of discourse that prioritises mention of practical applications (refer to section 4.5: p. 146); and 2. the Linear-Model-like storylines of the wider impact of curiosity-driven enquiry (refer to section 5.2: p. 157). When analysed, the empirical elements of these claims reveal limitations, but, to clarify, I have no intention of claiming that the members of the particle physics community I encountered are duplicitous, but rather seek to present the characteristics of their interactions with non-members of their community. In other words, EIDA has enabled me to uncover the members of the particle physics community's management of their hierarchy of interests, in which the pursuit of pure understanding takes precedence over the uses of research. I argue that this discursive logic implies the importance of protecting 'curiosity' for the particle physics community in the context of pragmatic science policy.

Within the Science Policy community and SPS literature, presumptions about the value and importance of curiosity-driven research relate to the 'Mode 1' knowledge production of scientific research, which is discipline-based and has high uncertainty in its applicability to complex problems beyond the disciplinary research community (refer to section 2.2: p. 56). I argue that the characteristics of 'Mode 1' research are evident in the way particle physicists depicted themselves in interview (refer to sections 4.1 and 4.2: from p. 123 on), remarking on their 'innate inquisitiveness' to explain their career choice. Moreover, because the interview structure was designed for non-members of their community (represented by me) to interact with particle physicists, and explore the value and importance they claim, it can be found that particle physicists' self-depiction and own preferences are accompanied by rhetorical emphasis of the superior epistemic status of particle physics research in comparison with other curiosity-led scientific disciplines, such as chemistry and astrophysics. As a result, I argue that the hierarchy of sciences presented can be understood as particle physicists' hierarchy of interests, creating tension with STS and SPS aspirations for a new form of socially robust and collaboratively assured science: the so-called 'Mode 2' knowledge production.

As I have detailed in this thesis (refer to sections 4.3 and 4.4: from p. 133 on), the tendency of particle physicist interviewees to shift from an authoritative account to a flexible interpretation in intellectual discussions about the uncertain and unknown part of their knowledge indicates the importance of social interactions. In other words, in order to be understandable and acceptable, I argue that assertive claims for the 'fundamental' importance of particle physics have to strike a balance with the evidence-informed policy trend. To clarify, I do not claim these particle physicists provided contradictory or untrue accounts, but I emphasise the contextual dependency of their justifications in the interviews, or in other words, the 'boundary-works' (Gieryn, 1983) of their self-presentations. In combination with similar discourses relating to public outreach and strategic documents (refer to sections 5.2 and 5.3: from p. 157 on), the patterns of these justifications have become 'cultural cartographies' (Gieryn, 1999: 21) of the European particle physics community in response to pragmatic science policies in the UK and Europe, the evaluations of which are often dependant on actors' accounts of their own actions.

For example, the typical way particle physicist interviewees explain the value and importance of particle and high-energy physics research to the general public and policymakers alike, not only has a specific narrative order that depicts the research community as greatly concerned with the practical applications of research, but also accumulates a broad spectrum of wider impacts from particle physics that appear to exemplify a linear influence from science on technology, innovation, economy and society (refer to section 5.2: p. 157). Combining these findings, we can observe that particle physicists' opinions and actions are intertwined with both external expectations and internal considerations, and thus these cross-boundary interactions and collective practices call for close scrutiny by the STS and SPS communities. However, we can see in sub-sections 5.2.1 and 5.2.2 (from p. 158 on) that neither the invention of the transistor nor the internet innovation led by the World Wide Web (WWW) was solely or directly contributed to by particle and high-energy physics knowledge and technology. That is to say, it is difficult, or even irrelevant, for particle physicists to provide personal experiences in practical applications of their research. Hence, I argue that my research provides an insight into the particle physics community by recognising the rhetorical fallacy that interactive discursive management may induce. Since the storylines about these inventions and innovations have become 'evidence', inscribed in strategic documents and communicated to society to influence the opinions of non-particle physicists (refer to section 5.3, from p. 172 on), members of the particle physics community have to consider the possibility that these evidence-like claims might encounter a detailed examination by the public funding agency.

Furthermore, although the main argument of Calvert's (2002) doctoral research on the construction of 'basic research' has shed light on the interdependency between the definitions of, and justifications for, basic research, and the reasons for and purposes of funding research, she noted that these reasons are *'dependent on our society's values and priorities'* that are *'fundamental political and moral questions [...] beyond the scope of a single DPhil thesis'* (Ibid.: 247). Therefore, my doctoral research is a further enquiry into the relationship between justifications for scientific research and the underlying and intertwined values and priorities. The interconnection between the values and priorities of science and society is indeed an immense topic beyond the scope of any single research project, including my PhD thesis. However, I argue that the publicity following the discovery of the Higgs boson and related justifications for curiosity-driven particle physics research in the 21st century have provided a temporal-spatial-specific nexus in which to study the ongoing negotiations of these values and priorities. Participating in the scientific and cultural phenomenon of the discovery of the Higgs boson enabled me to take EIDA as my methodological approach: I regard this to be the most appropriate lens with which to investigate the ways people build up value propositions for their knowledge and stances in interactive settings.

I argue that an understanding of this relationship is especially important in an era that prioritises the need to confront societal challenges and deliver societal benefits, as the cultural repertoires that represent curiosity-driven scientific research in traditional ways will have repercussions on how we think about and practise the way we engage with science and its responsibility. That is, we tend to leave the responsibility of impact to curiosity-driven scientists themselves and expect to derive the direct benefits from science that pursues knowledge. I argue that there is a danger of reproducing existing perceptions about science in a changing era: once the scientific community falls short of meeting the latest expectation or normative request, it will be criticised for this. I believe this is what the members of the particle physics community I studied wish to circumvent, as their discursive arrangement and storytelling aim to avoid such conflict in cross-boundary interactions. This does not imply that I endorse the imposition of pragmatic policy agendas on curiosity-driven science but reflects my pragmatic and positive attitude towards mitigating the tension between emerging policy cultures and scientific traditions.

Through analysis of my interviews with particle physicists, I have also found that a pronounced interest in curiosity-driven enquiry mirrors a relative lack of interest or participation in developing the practical uses of research, which, I argue, lies on the bottom level of the European particle physics community's hierarchy of interests. The particle physicists did not instantly refer to this 'un-interest' and were able to provide examples of the wider importance of particle physics research (refer to section 4.5: p. 146), yet it was noteworthy that the examples given – the WWW, transistors, particle therapies and nuclear-medical imaging – originated some distance from the interviewees' own research topics and expertise but close to popular imagery of the curiosity-driven particle physics community. Following these iconic examples, I probed for personal opinions about, and experiences in developing the practical benefits of their research, and received largely negative answers. I therefore argue that particle physicists' accounts of the usefulness and benefits of particle physics research have two variants: 1) A general version that echoes the pragmatic expectations of the science policy agenda; 2) A personal version that echoes the research community's hierarchy of interests.

I conclude that, given the growing prominence of the STS and SPS work that promotes the new or co-production of post-academic science (e.g. Etzkowitz and

Leydesdorff, 2000, Ziman, 2000, Nowotny et al., 2003, Jasanoff, 2004, read more in section 2.2: p. 56), this relative ‘un-interest’ of the particle physics community might be problematic for the current and future social relations of science. Again, I do not mean that the pragmatic policy trend is ultimately right and without the need of justification, but wish to raise awareness within the particle physics community, in order that they can consider alternative and sustainable interactions with the wider community. In fact, new interactions have been developing in the particle and high-energy physics community. As detailed in section 4.5 (refer to p. 146), particle physicists, to a certain degree, are familiar with the practice of public outreach and engagement. In addition, we also learnt in chapter 6 (refer to p. 189) that the KT group at CERN, especially since the Strategy proposal, in attempts to bring in the wider expectations and policy trend, has been stimulating new interest and practise within the research community. However, when asking about their everyday practices in my interviews with the KT practitioners at CERN, I was able to generate substantial discourse without frequent hierarchical discursive arrangements and rhetorical traps. Therefore, in the next section I will reflect on the findings in sections 5.4 and 6.3 (refer to p. 178 and p. 200) as a basis from which to suggest feasible interactions between scientific interest and policy expectations. It is my hope that the insights gained from these sections can enable us to move beyond mere awareness of the hierarchy of interests.

7.3 Co-producing the Motivations of Science

My research and interview questions about the wider importance of particle physics research reflect political and societal concern about the worth of publicly-funded curiosity-driven research. In my conclusion, particularly this section, my emphasis is not critical reflection on the appropriateness of wider concerns; instead, I take the practices stimulated by these concerns as a site to participate in, and observe how the relevant actors formulate a contextually-woven space for particle and high-energy physics research. Therefore, this section has implications for cross-boundary communication and interdisciplinary collaboration with particle and high-energy physics research. In the following two sub-sections, I reflect on the influence of the European particle physics community's hierarchy of interests on both evaluation practices within the science policy community and knowledge transfer practices at CERN. I also suggest ways for both the particle physics and science policy community to stimulate sustainable interactions between science and policy. In the final part of my conclusion, section 7.4, I will reflect on the impact of pragmatic policy agendas on the curiosity-driven research community and emphasise that a route to more amicable and productive interactions with the curiosity-driven research community is available.

7.3.1 The Obstacles to Research Evaluation and Public Engagement

I believe the replies particle physicists provided to my questions are interactive: not only reactive but active. Through science communication, public outreach and public engagement, the scientific community has become experienced in exercising its authority and publicly maintaining its credibility.

Moreover, these communicative and participatory practices of science have been promoted by the UK impact agenda as *'public engagement as a pathway to impact'* (RCUK, n. d.-a) and, since the *'science and society'* action plan[55], by European funded research programmes in a similar manner (EC, 2014). Given this context, I argue that we need to understand not only the research motivations of the particle physics community but also the strategy behind their wider communications and cross-boundary engagements. Having also applied EIDA to the way particle physicists explained their reasons for reaching out to the general public and the policy community, I discovered a similar hierarchical discursive pattern (refer to section 5.3: p. 172): that is, particle physicists revealed their own reasons for practising public outreach only after establishing policy intentions for public engagement. I conclude that accounts of the importance of public engagement revealed that ensuring the legitimacy of the research community was, unavoidably, of great importance to the research community itself. In other words, as guaranteeing benefits for public investors has become increasingly necessary, we cannot seek solutions for this from particle physicists' public engagement practices alone, as their main task is to continue research. In other words, the 'fusion' of two or more interests may be the cause of the complexity and ambiguity evident in cross-boundary interaction and communication. An awareness of this within the research community and a clarifying of the difference between interests

[55] The 'science and society' action plan became the 'science in society' action plan in 2007, and is now the 'science with and for society' action plan in the Horizon 2020 programmes of European Commission.

might enable the general public and policy practitioners to more advantageously comprehend and reflect on public engagement with science.

Moreover, this finding has serious implications for the assessment of public engagement outcomes. Leaving the intentions of particle physicists towards public engagement unconsidered has enabled the creation of a flexible discursive space in which the interests of this research community can be prioritised. For instance, the particle physicists I interviewed confused the concept of two-way public engagement with that of one-way public outreach, restricting opportunities for the general public and non-particle physicists to participate in any value construction (refer to section 5.3: p. 172). Again, the particle physics community's commitment to public engagement, as to the impact agenda, lacks further support for them to think and practise more beyond the representational stage. This interpretation of public engagement explains the way storylines for wider communications have been structured around the largely discredited Linear Model. These Linear-Model-like repertoires, which are also promoted in Strategy working documents (refer to section 5.2: p. 157), do not encourage both particle physicists and non-particle physicists to creatively brainstorm the value and importance of particle and high-energy physics research to society. I argue that the science policy community needs to reflect on this issue, as the implementation of policy may incur unexpectable and undesirable outcomes when divergent intentions are not understood.

In this regard, I make two suggestions to the SPS and science policy communities. Firstly, I argue that an understanding of a research community's interest in policy, as well as the policy influence on its research motivation, can be attained through the assistance of social scientists with expertise in EIDA, an assessment tool that can overcome the influences of cultural repertoires and examine the interaction between established scientific communities with emerging policy agendas and social responsibilities. In other words, I believe that EIDA can approach the values and priorities of the research community from the patterned characteristics of its justifications. Conversely, any robust justifications that may call the appropriateness of policy agendas into question will also be detected by carrying out the empirical work utilised for this thesis: a detailed analysis of the language-use, rhetoric, repertoires and narrative structures of small-sample-size, in-depth interviews.

Secondly, I advise the science policy community to take the insights presented above as incentive for the redesign of policy agendas, since the attitudes and behaviours of the relevant actors revealed here have been neglected in strategic policy planning. I acknowledge that EIDA is a relatively high-cost qualitative approach for the science policy community, which has to manage the research directions and funding allocations of distinctive scientific disciplines according to various social challenges. However, given the insightful findings it can generate, I believe that collaboration between the SPS and Science Policy communities could alleviate the cost of EIDA.

7.3.2 The Obstacles to Knowledge Transfer or Exchange

CERN KT officers have striven to co-produce the research motivations of their institution, but, as the findings I presented in chapter 6 (from p. 189 on) show, knowledge transfer practices for particle and high-energy physics research at CERN have had a limited effect on the hierarchical interests of the European particle physics community. I am not implying that CERN KT has had no influence on the research community's motivations and practices, but from the hierarchical discursive pattern of CERN KT practitioners justifying curiosity-driven particle and high-energy physics research (refer to section 6.2: p. 190), it is worth noting the Linear Model presumptions. Moreover, the evidence they provide to support the Linear-Model hypothesis either bears a remarkable similarity to the storylines used by particle physicists or is largely tangential to the specific body of knowledge relating to particle and high-energy physics.

My analysis of CERN KT practitioners' hierarchical accounts has revealed the rhetorical element of their support for curiosity-driven research. That is, although the European particle physics community presents a coherent account of the importance of particle physics, the KT officers' justifications are layered in a different narrative order, in which their personal interest is placed at the end of the discourse rather than at the beginning, and is focused on the applicability of research rather than satisfying curiosity. However, both sets of interviewees manage external interests and expectations before revealing their own. Consequently, both discourses reflect the hierarchical interest of the particle physics community, but with interests located at different levels of the hierarchy: the curiosity-enquiry of particle physicists is placed at the top, while the applied purposes of KT practitioners are less urgent. I conclude that scientific culture and its veneration of free enquiry, while not necessarily having a direct influence on the KT actors at CERN, does have a discursive impact. This influence can be uncovered through employment of EIDA.

Furthermore, when discussing their everyday practices, these KT officers frequently related the difficulties of transferring particle and high-energy physics knowledge and technology to industry and society without hierarchical discursive patterns (refer to sub-section 6.3.1: p. 202). Despite the fact that the methodology of this thesis is inspired by ethnomethodology and constructivist scientific discourse analysis (refer to section 3.4: p. 114), which focuses on the versions of reality constructed in various situations and does not judge the correctness of actors' claims by external criteria, I believe these recurrent expressions of difficulty—which are beyond the scope of the EIDA method—need to be taken seriously. To clarify, I do not attempt to suggest that one group of my interviewees is more credible than the other. Nonetheless, I do suggest we take note of the difficulties CERN KT practitioners recount, as their experiences reflect the European particle physics community's hierarchical interests, embodied by not only my Edinburgh interviewees' discourses but that of a high-level particle physicist representative on the CERN Council (refer to sub-section 6.3.1: p. 202). Due to concern about the Linear-Model-like imagery of particle and high-energy physics research, the KT actors at CERN may not take heed of accounts concerning the difficulty of transferring knowledge. Thus, this problem may well be underestimated by themselves, particle physicists and policymakers. I encourage both the research community and the science policy community to acknowledge the importance of EIDA in understanding implicit cultures, and squarely address discourse that, while containing little rhetorical management, may reveal an inconvenient truth.

In this sense, I further argue that knowledge transfer practice is not yet a collective interest at CERN, remaining subordinate to the epistemic interest of particle and high-energy physics research. However, there is a significant difference between particle physicists' and CERN KT officers' assumptions about the linear-model of innovation, with the latter arguing that to actually realise the wider impacts of research requires the knowledge producers'[56] interest, which has not been forthcoming (refer to point 6.3.2: p. 210). In other words, particle physicists' assumptions about the Linear Model, in which wider impact can be realised without the knowledge producers' interest and input, is opposed by CERN KT practitioners. Therefore, although particle physicists and KT officers share the same repertoire and culture, one which values the benefits of particle physics and curiosity-driven research in general, they have different understandings of the effective pathway to impact. At the heart of this disagreement are the obstacles to knowledge transfer activity at CERN, since these two sets of actors that represent the European particle physics community have yet to reach common ground on which to cooperate. I argue that the European particle physics community, as epitomised by the cases studied in this thesis, suffers from the colliding interests in the utility function and the understanding function of research. Furthermore, knowledge transfer practices at CERN cannot effectively modify the hierarchical culture and action priorities of this curiosity-led research community. Instead, it is

[56] There are not only particle physicists carrying out research and development at CERN but also experts in many other fields. Therefore, KT officers at CERN deal with a variety of knowledge and technology transfer projects and are involved with a diverse range of knowledge producers.

a negotiated process that unavoidably complies with the research community's existing interests and work culture.

That is to say, the European-wide science policy agenda, intended to transform the discipline-based epistemic interests of the scientific community into a focus on solving transdisciplinary societal challenges, has not achieved its goal through a knowledge transfer programme implanted in the particle physics community. Nevertheless, at the representational level, this lack of interest or participation in knowledge transfer by the majority of European particle physicists is rarely evident in review reports and public discourses. Since we have been familiar with Linear-Model constructions by scientists and policymakers, and relatively unfamiliar with the actions of KT practitioners on the front line, I suggest we can experiment by raising scientists' interest in knowledge transfer as a way of developing and expanding knowledge transfer practices and the implementation of policy agendas. In fact, there are CERN KT officers responsible for holding informal meet-ups with CERN scientists, where they drink, chat and contemplate the usefulness of knowledge[57]. While not an instant solution to the problem, I believe in the long run this will help bridge diverging scientific motivations by increasing mutual understanding. Nonetheless, this kind of social experiment has to be cautious about overly imposing external interests.

[57] The record of these meet-ups can be found at: https://kt.cern/entrepreneurship-meet-ups

7.4 Further Reflections and Recommendations

As the credibility and validity of sociological research is of great importance I will now return to my methodology. For this thesis, I employed a micro-sociological lens to inspect the social-cultural phenomenon resulting from the discovery of the Higgs boson and particle physics research, and asked the question *'What is the worth of particle and high-energy physics research and why is it presented in the way it is?'* My intention has not been to research the academic significance of particle physics but to understand interactions between the scientific and policy communities that 'co-produce' the value and status of particle physics research in society. The theoretical contributions and policy recommendations of this thesis have resulted from the use of EIDA to study patterns of rhetoric, discourses, storylines and narrative strategies in detail, a process that can only be achieved through studying a few cases at a time.

Although the small sample size is a major limitation of my doctoral research, I argue that through a research design comparing interview data with the documents I collected, investigating accounts by both particle physicists and CERN KT officers, as well as triangulating the discursive patterns of Edinburgh particle physicists with a particle physicist representative on the CERN Council, it is still possible to some extent to generalise a wider picture of the European particle physics community's cultural responses to external expectations and mandates. In other words, as stated in my reflection on the epistemological beliefs of constructivist scientific discourse analysis led by Mulkay and Gilbert (refer to section 2.5: p. 76), I believe in and aim to connect the discursive patterns of actors with the relatively stable social realities of their attitudes: the orientations of their speech and practices. Nonetheless, I certainly cannot claim to have determined the ultimate reason for the European particle physics community's behaviour, since the multiple social worlds influencing the making of realities cannot be explored in a single study.

Multiple social worlds, interest groups and their interactions mean the balance between the understanding function and utility of knowledge enquiry is in need of constant discussion and negotiation. Moreover, these discussions and negotiations are inseparable from discursive or representational practices that entail interpretative flexibility and an element of performance. Thus, they do not necessarily reflect objective facts or evidence. However, by calling attention to the possibility of empirically exploring the recurrence of an individual's attitudes through patterned discourse, I hope to have demonstrated that understanding the reason and purpose of making claims is possible. The findings of this thesis, therefore, help us delve deeper into the reason for and purpose of science. In addition to empirical implications, I believe that my research can advise the SPS and science policy communities on the relationship between science and policy. Through an examination of recurrent patterns, I have found that the justifications and evidence of the value or worth of particle physics presented are neither a complete reflection of external expectations nor the blunt revelation of particle physicists' epistemic interest. Rather, these value claims embody a hierarchy of interests, in which internal concerns carry greater weight and protection of the research community's epistemic goal is imperative. However, Linear-Model-like storylines and the narrative prioritisation of external expectations, which occurred repeatedly in interviews and documents, suggest particle physicists have shared linguistic registers to manage communications beyond the research community and create publicly acceptable interpretations of their motives. In sum, understanding and governing the value and importance of scientific research requires the acknowledgement of the delicacy of interactions between the scientific community and wider society.

Hence, in practice, I suggest the science policy community not only evaluate the European particle physics community's research outcomes and impact practices but also empathise with the interests of the research community. While raising the research community's interest in public engagement is important to ensure such a practice benefits the public and engenders mutual interaction between science and society, it is equally important to understand the research community's intensive attention devoted to free enquiry; while evaluation of the wider impacts of research also demands scrutiny of interests to differentiate between representations and behaviours, interaction might be improved if the science policy and SPS communities reflect on the Linear-Model culture that can exaggerate the direct influence of science. Preliminary discussions about REF (Research Excellence Framework) 2021 have advised that reported case study impacts must have been produced between 2000 and 2020, and occurred between 2013 and 2020 (REF, 2017: 7), implying that REF has recognised the need to assess the quality and relevance of impacts rather than their symbolic existence. Under such a measure, the ubiquitous examples of particle and high-energy physics contributions – the WWW and the transistor – are no longer valid proof of a research community's current impact. This definition of impact will definitely affect particle physics and other curiosity-driven research communities. I argue that, aside from establishing a rigid time-frame for the evaluation of research impacts, active engagement with the scientific community's research motives is required if we hope to transform the conventional culture and attitude of the curiosity-driven particle physics community.

Although not explicitly discussed in the interviews, given the substantial time and effort required to bridge the interests of particle physicists, CERN researchers, KT officers and industry, it is evident that the cost of knowledge transfer practices at CERN is high. I argue that this culture of the European particle physics community's hierarchical interests has exceeded the capability of the small KT group at CERN. CERN KT is not currently able to conduct cost-benefit analyses and follow-up studies on the actual impact of knowledge transfer projects; neither can it change the role descriptions of other staff at CERN, whose duties do not include knowledge transfer. Consequently, if enhancement of knowledge transfer practices within the research community is desired, I propose making this aspect part of the role descriptions of researchers in particle and high-energy physics research, and possibly in other 'basic research' communities. This would not only reduce the cost of knowledge transfer activities in curiosity-led research communities, less effort would need to be expended on mitigating the tension between the interests in practical applications and pure enquiry. It is important to differentiate between merely adding one more responsibility to a scientist's role and the thorough reassessment of their duties; while the former would be more convenient than redesigning the entire system, overloading scientists is unlikely to stimulate new interest. There would certainly be a process of adaptation to such structural change, but I believe this is the only way to reform conventional disciplinary science in relation to the issues of wider impacts and the social responsibility of research.

There may be opposition to the idea of adding this responsibility to the work of curiosity-driven scientists, and arguments that no space for pure enquiry would remain. However, I argue this opposition neglects the possibility of the 'Linear Model' meeting expectations. If we continue to believe that pure scientific enquiry has the potential to result in technological and innovative impacts on society, as the model promises, knowledge transfer practices are therefore inseparable from curiosity-led scientists' everyday research. Hence, making the duty to transfer knowledge and deliver wider impacts explicit is not necessarily a constraint but a reminder for both scientific and policy communities to interact with the unavoidable wider culture. In addition, with the assistance of KT practitioners who have received the training and professionalisation recommended in contemporary policy agendas, I argue that incorporating interest in applications into curiosity-driven research would not necessarily reduce the capacity of scientists. As Rip (2002) has pointed out, it is likely that multi-disciplinary and application-oriented research has already been undertaken in traditional research communities. I argue that research based on a shared interest and value would construct a more stable and sustainable scientific culture in the future.

There may be concern that an increase in the science policy community's authority would result in the effects of their interests being neglected. However, I argue that such fears could be allayed by also applying EIDA to science-policy discourses in the STS and SPS communities, thereby revealing whether they speak for the self-interests of a particular stakeholder group or the collective interest of multiple social groups. It is undeniable that I am taking a political stance through my doctoral research, calling for active governance of publicly-funded scientific research and distribution of the benefits of that research. However, I argue that my political stance speaks not only for my own interest but the interests of society. As Calvert (2002: 245) has stated, *'[m]aintaining that basic research is ''knowledge for its own sake'' implies that it is beyond the reach of ordinary mortals who are not scientists, and ignores the needs of wider society'*. The intentions of publicly-funded scientific research, whether in physics, policy or any other area, should also consider other stakeholders.

Curiosity-driven physics research, directed towards the accumulation of knowledge, has an enduring cultural status in Western civilisation and an emerging authority in other parts of the world. Thus, its value and importance have symbolic implications that cannot be understood merely in economic terms and practical benefits. I am not attempting to deny the cultural value and importance of particle physics in this thesis. Rather, my aim has been to address the conflict between traditional scientific culture and contemporary science policy agendas. In response to a changing funding environment that expects impact and social responsibility, I suggest the particle physics community reflects more actively upon its hierarchy of interests and incorporates an interest in the applied purposes of research into its research motivations. I believe transformation of the particle physics community's hierarchy of interests will benefit particle physicists themselves, by renewing rather than negating the field's cultural value and significance in society. For example, in the plans to construct a 'Future Circular

Collider' at CERN, in which particle physicists will be able to further explore their research questions, attempts have also been made to address potential practical impacts (Zimmermann & Benedikt, 2018). In the future, I plan to explore the ongoing negotiation and legitimation of the particle physics community's interests in non-UK and non-European contexts and examine the interaction of the curiosity-led research community's goals with the changing science policy agenda of impact and social responsibility.

Appendix A

Interview guide for particle physicists

I. Personal trajectory

1) What are your educational background and work experiences?

2) What motivated you to do particle physics research?

3) What are your research areas and why did you choose them? What is the value and importance of your research and particle physics in general?

II. Public communication experience

4) Can you share your experiences communicating with non-particle physicists in general, and in writing and reviewing proposals, funding applications, annual reports or public outreach materials?

5) How did you explain the value and importance of particle physics research in public communications? Have you developed any skills or strategies for such circumstances?

6) Can you also share your experiences introducing new concepts or practices from beyond particle physics to the community?

7) How did you explain to your colleagues the importance of considering external ideas and practices? How were these new approaches received by the research community?

III. Particle physics in a wider context

8) How is particle physics perceived beyond your community? Do you think society and/or the policy community share the same perspective as you?

9) What do you think about the funding and policy environment for science? Does the need to communicate the value of particle physics affect your research? How?

10) What can a particle physicist contribute to society and how? Are you and the research community making such contributions as part of your work?

Appendix B

Interview guide for knowledge transfer officers

I. Personal trajectory

1) What are your educational background and work experiences?

2) What is your responsibility in the particle physics community? What motivated you to conduct knowledge transfer for particle physics?

3) Do you have any experience in knowledge or technology transfer for other types of research? What is the value of particle physics and is this different to other sciences?

II. Cross-boundary communication experience

4) Can you share your experiences when communicating your knowledge transfer projects with members of the particle physics community, industry and the supervision board? Are these experiences different from your past work experiences?

5) How did you explain the value and importance of knowledge transfer for particle physics in these communications? Have you developed any skills or strategies for these circumstances?

6) In general, is the particle physics community interested in knowledge transfer? If not, how do you and your colleagues manage different interests in the research community?

7) What are the challenges of your work? Do you evaluate and assess knowledge transfer projects for particle physics research?

III. Particle physics in a wider context

8) How is particle physics perceived beyond the particle physics community? Do people from the industry share the same view as you? Why/why not?

9) What do you think about the funding and policy environment for science? Does the need to communicate the value of particle physics affect particle physics research? How?

10) What can particle physics contribute to society? Are you and your colleagues facilitating such contributions? Why/why not?

Appendix C

List of Edinburgh particle physicist interviewees[58]

Particle physicist interviewee list-					
No.:	Group:	Status:	Managerial experience:	Origin:	Gender:
1.	Experiment	Senior	Y	UK	M
2.	Theory/experiment	Retired	N	UK	M
3.	Experiment	Senior	Y	Europe	M
4.	Theory	Mid-level	N	UK	F
5.	Anonymised				
6.	Industry	Mid-level	Y	UK	M
7.	Theory	Senior	Y	UK	M
8.	Instrument	Mid-level	Y	Europe	M
9.	Experiment	Mid-level	Y	UK	F
10.	Experiment	Postdoc	N	Latin America	F
11.	Theory	Postdoc	N	Russia	M
12.	Theory	PhD student	N	Europe	M
13.	Theory	Retired	Y	UK	M
14.	Anonymised				

58 Gender and country of origin are significant variables in social research, but were not investigated here as the professional identity of my research objects is of greater relevance to this thesis. Nevertheless, I did keep track of these attributes to ensure the diversity of my interview sample.

15.	Experiment	PhD student	N	Africa	M
16.	Experiment	PhD student	N	UK	M

Appendix D

List of CERN interviewees

CERN interviewee list-					
No.:	Background:	Position:	Managerial role:	Origin:	Gender:
CERN 1.	Electronic engineering, PhD	Group leader	Y	Europe	M
CERN 2.	Cosmology, PhD	Communication and marketing officer	N	UK/ Europe	F
CERN 3.	Intellectual property law, Master	Section leader intellectual properties	Y	Europe	M
CERN 4.	Aerospace engineering, Master	Aerospace applications coordinator	N	Europe	M
CERN 5.	Anonymised				
CERN 6.	Entrepreneurship and business development, Master	Entrepreneurship development officer	N	Europe	F
CERN 7.	Computer science, Master	Knowledge transfer officer	N	UK/ Europe	M
CERN 8.	Biomedical engineering, PhD	Knowledge transfer officer	N	UK/ Europe	M
CERN 9.	Biochemistry, PhD	Medical applications officer	N	Europe	F

CERN 10.	Engineer, Master	Head of partnerships and fundraising (ex KT officer)	Y	Europe	M
CERN 11.	Management, Master	Trusts and foundations officer (non-KT)	N	Europe	F
CERN 12.	Particle physics, PhD	Council chair	Y	Europe	M
CERN 13.	Anonymised				

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