PARTICLE PHYSICS AND PUBLIC ENGAGEMENT: A MATCH MADE IN MINUSCULE MATTER

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Abstract

Public engagement with science and technology, or PEST, is a field of growing practice and study. There remain, however, notable gaps in our understanding of the attitudes of researchers towards public communication of science itself, particularly from fields of fundamental research that continue to be under-represented in our literature. The attitudes towards public engagement within the particle-physics community have been investigated in the doctoral research project described here.

The community under study is represented by the Compact Muon Solenoid (CMS) collaboration at CERN, the European Organization for Nuclear Research, sometimes known as the European Laboratory for Particle Physics. The collaboration takes its name from the CMS experiment, a particle detector it operates at CERN's Large Hadron Collider (LHC), the world's largest and highest-energy particle collider. CERN estimates that around half of the global community of particle physicists conduct their research at CERN.

The attitudes were explored through a mixed-methods approach grounded in pragmatism, with a collaboration-wide web-based survey, yielding 391 valid responses, followed by 19 personal interviews chosen by purposive sampling and conducted either in person or over a video call. The majority of the survey respondents showed favourable attitudes towards public engagement, sometimes also known as "outreach", with scientists seeing participation as a duty and participating in public engagement without being required to. Belonging to a large research collaboration was also seen as advantageous for the purposes of outreach participation, partly because a sizeable group of researchers has a sense of shared responsibility towards a specific area of science, allowing resources to be shared and dedicated communications professionals to be hired.

There was a strong pedagogical bent to the types of public engagement scientists seek to participate in, with participatory paradigms ruled out by the majority of both survey respondents and interviewees. The practice of fundamental research was also framed by the interviewees as a cultural practice, taking physics back to its roots in “natural philosophy”.

The thesis concludes by recommending that evaluation of public engagement with science and technology consider the relative “relevance-distance” – the degree to which the field of research in question holds relevance to everyday human life – in determining what modes of engagement are suitable for a given field of research, so as not to paint fundamental sciences with a brush more suitable to applied fields of research. Further, as science-in-society research has made the case for there not being a single, homogeneous “public” but many self-identifying *publics*, depending on context, interest and relative levels of expertise, the fields studying the interplay between science and society need to think of PEST as public engagement with *sciences* and *technologies*, that is, in the plural, and resist the temptation to make sweeping generalisations about the applicability of our research findings and policy recommendations to a single, monolithic, uniform “science”.

Résumé

L'engagement du public dans le domaine des sciences et technologies (« Public engagement with science and technology » en anglais, ou PEST) prend une place croissante et est de plus en plus étudié. Certains aspects sont cependant moins documentés, comme la position des chercheurs sur la communication publique des sciences et technologies. C'est le cas en particulier dans le domaine de la recherche fondamentale, sous-représenté dans notre littérature. L'attitude des scientifiques à propos de l'engagement du public dans le domaine de la physique des particules ont été étudiées dans le cadre du projet de recherche doctorale décrit ci-dessous.

L'étude porte sur la communauté des scientifiques de la collaboration CMS (Solénoïde compact pour muons) au CERN, l'Organisation européenne pour la recherche nucléaire, également connu sous le nom de « Laboratoire européen pour la physique des particules ». La collaboration CMS exploite un détecteur sur le Grand collisionneur de hadrons (LHC) du CERN, l'accélérateur de particules le plus grand et le plus puissant du monde. Selon le CERN, environ la moitié de la communauté mondiale des physiciens des particules effectue des recherches sur les expériences du CERN.

Les opinions et comportements des scientifiques ont été explorés par le biais d'une approche mixte et pragmatique, sur la base d'une enquête en ligne à l'échelle de la collaboration. Cette enquête a récolté 391 réponses valides. Elle a été suivie de 19 entretiens, choisis par échantillonnage non probabiliste, menés soit en personne, soit par appel vidéo. La majorité des scientifiques qui ont répondu à l'enquête ont exprimé une opinion favorable sur l'engagement public, parfois également appelé « sensibilisation ». Les scientifiques participent à cet engagement public volontairement, considérant même cette participation comme un devoir. Être membre d'une grande collaboration de recherche est considéré comme un avantage pour la participer à la sensibilisation, en partie en raison du sentiment de responsabilité partagée au sein d'un groupe important de chercheurs, permettant également de mettre les ressources en commun et d'engager des professionnels de la communication.

Les actions d’engagement public auxquelles les scientifiques cherchent à participer ont une forte connotation pédagogique. Les paradigmes participatifs - dans lesquels le public est impliqué dans le processus de recherche - sont exclus par la majorité des répondants à l’enquête et des scientifiques interviewés. La pratique de la recherche fondamentale a également été présentée par les personnes interrogées comme une pratique culturelle, ramenant la physique à ses racines dans la « philosophie naturelle ».

La thèse conclut en recommandant que l’évaluation de l’engagement du public dans le domaine des sciences et technologies tienne compte de la « distance de pertinence » relative - le degré de pertinence du domaine de recherche pour la vie humaine quotidienne. Ce critère permettrait de déterminer les modes d’engagement adaptés à un domaine de recherche donné, afin de ne pas traiter les sciences fondamentales comme le seraient les recherches appliquées. Par ailleurs, les recherches sur la science et la société ont démontré qu’il n’existe pas un « public » unique et homogène, mais de nombreux publics qui se définissent en fonction du contexte, de leur intérêt et des niveaux d’expertise. Les études des interactions entre science et société doivent par conséquent considérer l’engagement public (PEST) comme un engagement *pluriel* du public envers *les sciences* et *les technologies*, et éviter de généraliser à l’extrême l’applicabilité des résultats des recherches et des recommandations à une science qui serait unique, monolithique et uniforme.

Gratitude

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Which brings me to Gilles Raymond: thank you for helping me out with access to all of the CMS internal resources needed for this PhD and for being the first person to show me how to connect to a remote server from the terminal. Thanks also to Tiziano Camporesi (then CMS Spokersperson) and Jorgen D'Hondt (then CMS Collaboration Board Chair) for approving the research project on behalf of CMS. My thanks also to Maarten Wilbers, Karen Ernst and Sofia Intoudi from the CERN Legal Service for approving my research protocol on behalf of CERN. I am also grateful for all the help that Tania Pardo, Zsuzsanna Garai, Jennifer Dembski and Anna Yaneva gave me, no matter how big or small my request.

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Some friends become family and you often wonder how there could ever have been a time when you did not know one another. My dear Tushna Commissariat is one such friend, who has been an endless source of strength. Thank you for always having a place for me to crash at, whether it's for a weekend, a week or months at a time!

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I have had the misfortune of having two grandmothers watch me start this journey but not finish. They remain inspirations to me, and I am grateful for all that they have done in making me who I am today.

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And finally, this PhD would never have reached this point if not for the unflinching support Julieta Arancio has given me since the day we met. Thank you, Juli, for the music and the magic that you bring to my life every day. Thank you for your love and patience, and thank you for being you. Sos la mejor.

In loving memory of my father

Maheshchandra B. Rao

17 July 1948 – 10 July 2012

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The effort to understand the universe is one of the very few things that lifts human life a little above the level of farce, and gives it some of the grace of tragedy.

Steven Weinberg

Chapter 1

Introduction

DOOMSDAY PREDICTIONS TYPICALLY arise from the examination of religious texts, but in 2008 it was the field of fundamental physics that provided the exact date – 10 September that year – when the world was supposedly going to end. The epicentre for this destruction was to be CERN, the European Organization for Nuclear Research, also known as the European Laboratory for Particle Physics. Panic had spread because some people feared a black hole would be produced when CERN circulated protons inside the Large Hadron Collider (LHC) for the first time that day. The media perpetuated the panic by repeating the claims of the protesters, who filed court cases in the USA and in Europe to prevent the machine from being switched on. Physicists, aided by professional science communicators, from CERN and around the world reassured them that there was no risk. When the presentation of facts and credentials failed, prominent physicists appeared on American prime-time television shows and hoped that a comedic take might prove more useful. In the end, the fears proved unfounded. The scheduled day arrived, the LHC circulated its first proton beams, and the world's most powerful particle accelerator has been in operation ever since (Chalmers, 2018).

High-energy particle physics does not usually get the attention that it did in September 2008. In fact, as Figure 1.1 shows, CERN has not attained the lofty heights of worldwide news coverage since. However, interest in the field arguably took off with the publication of *The God Particle* by Lederman (1993), which gave the world a popular introduction to the Higgs boson. By the early 2000s, CERN began to develop a coherent communications strategy and a greater number of particle physicists got involved in the public communication of their research. This thesis seeks, broadly, to ascertain the attitudes that the community of particle physics has towards this public communication, to identify their motivations for participating in such activities and the reasons why they may be prevented from doing so.

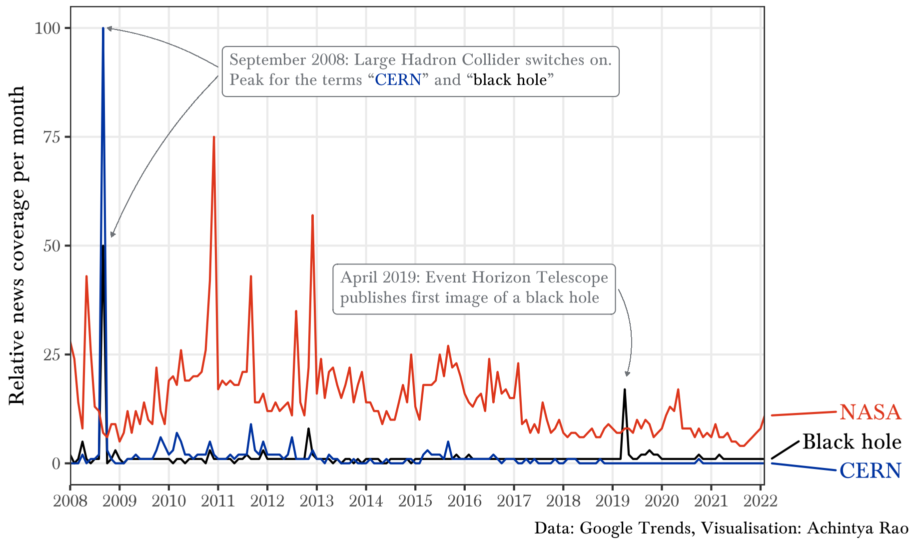

Figure 1.1: CERN's relative news coverage worldwide peaked in September 2008

1.1 CERN and public communication

CERN is the world's largest laboratory for particle physics. Located in the outskirts of Geneva, Switzerland, it was established in 1954 to bring together scientists from European nations in order to pursue research for peaceful purposes. Scientists from around a hundred countries come to CERN for their research. A few are based permanently at CERN, often still employed by their home institutions, but many are only short-term visitors. The long- and short-term visiting researchers are called "CERN Users". As a laboratory, CERN operates the aforementioned LHC, the world's biggest particle accelerator, and the one with the highest particle-collision energy ever attained under human-made conditions (Evans and Bryant, 2008). Four major research collaborations operate their particle detectors at the LHC, using data from the collisions produced by the machine to search for new particles and probe the laws of the universe.

The organisation is also active in public communications, especially at the local level. On site are two public museums with a major science centre – called Science Gateway* – under construction. Before the pandemic, CERN would play host to over 100,000 visitors each year, being able to satisfy only a fraction of the more than 300,000 requests. Visitors to CERN get to see some of the operational or experimental areas of the laboratory and are guided by scientists, engineers and communicators on a

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*https://sciencegateway.cern/

voluntary basis. CERN is rated as one of the top visitor destinations of Geneva, despite being on the very outskirts of the canton of Geneva. The laboratory also organises open days every five or six years, receiving up to 70,000 visitors on site over a single weekend.

In addition, scientists based at CERN participate in a variety of local and international activities that bring particle physics into school classrooms. These include the International Physics Masterclasses, in which over 10,000 high-school students per year step into the shoes of a physicist and spend their day analysing real collision data from particle detectors located at the LHC. Most of these activities rely on the participation of CERN Users.

As a source of data to represent an entire field of study, few places could compete with CERN. In 2015, CERN estimated that – with some 12,000 visiting scientists from across the globe – approximately half of all particle physicists worldwide come to CERN for their research (CERN, 2015). The community of particle physics is also comparatively close-knit. Due to the sizes of the infrastructure needed to run particle-physics projects, large groups of people, numbering in the hundreds if not thousands, work together in collaborations whose sizes were previously unheard of (Traweek, 1992). Outside of CERN itself, communication efforts within the community are directed by national laboratories or bodies representing the entire country's particle physicists and are coordinated by organisations such as the International Particle Physics Outreach Group (IPPOG), the European Particle Physics Communications Network (EPPCN) or the InterActions collaboration.

1.2 The Compact Muon Solenoid collaboration

The CMS Collaboration is one of the many international collaborations based at CERN. It is named after the Compact Muon Solenoid, one of the LHC's four major particle detectors. The collaboration consists of over 4000 physicists, engineers, technicians and administrative staff, representing around 200 institutions across more than 40 countries. With over 80 nationalities in the collaboration as well as members with a variety of academic positions, CMS serves as a source of a wealth of data on the attitudes of the particle-physics community towards science communication.

CMS has a Communication Group that reports directly to the Collaboration Board, which can be thought of as the parliament of the collaboration. The Communication Group is responsible for coordinating public-communication activities for all of CMS. The activities of the CMS Communication Group include maintaining the public website of the collaboration, coordinating with the CERN communication teams (including the Press Office), organising local communication events at the CMS experimental site, and assisting members of CMS in their own communication endeavours. CMS members regularly collaborate with researchers from the other LHC collaborations on matters of public communication.

1.3 Research questions

In recent decades, there has been growing scholarship into public communication of research, particularly into what is sometimes known as public engagement with science and technology, or outreach. Science-communication scholars have examined how scientists the type of outreach activities scientists participate in, whom they prefer to communicate with beyond their scientific peers and why they choose to do so. They have also scrutinised the objectives behind outreach activities according to scientists and the outreach mandates of research funders, and have studied in a variety of domains of research the different paradigms of public communication, which can range from scientists delivering public lectures to seeking citizen participation in shaping the outcomes of the research being undertaken. This doctoral project seeks to extend science-communication scholarship to the domain of particle physics.

The particle-physics community is seemingly active in public communication as a whole, coordinated by laboratories and international organisations around the globe. The field also receives regular media attention and has made the front page worldwide in recent years with the discovery of the Higgs boson. Despite being a tight-knit community, the researchers report to a variety of funding agencies in different countries, each of whom has differing mandates for public communication of research. This thesis therefore seeks to answer four research questions concerning particle physics and outreach:

1. **RQ1**: "What are the attitudes towards outreach within the particle-physics community, including the motivations for – and barriers against – participating in outreach activities?"
2. **RQ2**: "Do these attitudes towards outreach within the particle-physics community vary with respect to age, gender and outreach experience?"
3. **RQ3**: "How, if at all, are these attitudes influenced by (a) differing expectations from funding bodies and (b) being part of large, international collaborations?"
4. **RQ4**: "Are participatory paradigms present in the discourse concerning outreach within the particle-physics community, and what is the perceived relevance of the research to the everyday lives of non-specialists?"

1.4 Outline of chapters

This thesis is divided into seven chapters, including this one.

Chapter 2 provides a literature review covering research and scholarship on public engagement with science. It charts the history of the various paradigms regarding the nature of the relationship between science and society, and includes reflections on the paradigm *du jour*. The chapter also highlights various studies conducted to assess the attitudes of scientists to public engagement, and wraps up with a look at public engagement in the context of particle physics.

Chapter 3 describes the methodological framework for this research. It describes the choice of method adopted, the target population for the study, the various steps that were taken to collect and then analyse the survey and interview data, and includes a brief overview of the research data management adopted for this project.

Chapter 4 presents a quantitative analysis of the survey data collected as part of this research. It includes demographic information about the survey respondents, descriptive statistics for several of the statements used to evaluate the attitude of the respondents, and an exploratory factor analysis to determine the underlying factors that describe the dataset obtained from the survey.

Chapter 5 shows the results of a thematic analysis performed on the data collected from personal interviews. The demographic information of all the interviewees is first provided, after which the six themes identified from the analysis are discussed in detail.

Chapter 6 synthesises the results of the two analyses in order to address all four of the research questions, and compares the findings obtained to the wider body of literature on the subject.

Chapter 7 concludes the thesis by discussing the key outcome of this research (i.e. the concept of "relevance-distance"), the implications and recommendations arising from the findings, the limitations of the research project and future directions to explore.

1.5 Personal motivation

A doctoral thesis, as I have learnt, is a deeply personal work. In my case, it sat at the intersection of my academic interests and my processional work. I spent over ten years as a science communicator at CERN (seven-and-a-half years with the CMS collaboration), including over most of the period of this doctoral work. In my early years at CERN, I was amazed by the variety of science-communication activities that CMS engaged in. I embarked upon this research to uncover the attitudes that the scientists

– on CMS specifically but at CERN and beyond more generally – had towards the public communication of their research.

Even though CMS supported my work (under the aegis of the CERN Doctoral Student Programme for three years), I had complete academic freedom to pursue the research questions as I felt best. Nonetheless, being embedded as a professional science communicator within the same community who's attitudes towards science communication you intend to study has great potential to influence your outlook and consequently the research. The ethics of this project and my positionality within it are discussed in § 3.7.

Chapter 2

Literature Review

OUR CONTEMPORARY VIEWS regarding science communication can trace their origins to the end of the Second World War, when science and engineering, and in particular fundamental physics, gave the world nuclear power, the semiconductor and Sputnik. Humanity entered the age of atomics, electronics and spacefaring (Hurd, 1958). It was around this time that scientists in the USA and Western Europe concluded that members of so-called "lay society" should possess a basic knowledge of scientific facts, given the increasing influence of modern scientific and technological outputs – such as the television sets and transistor radios – on everyday life.

2.1 Science literacy and a knowledge deficit

According to Hurd (1958, p.13), "Attempts to define human values, to understand the social, economic and political problems of our times, or to validate educational objectives without a consideration of modern science are unrealistic." In introducing and popularising the phrase "science literacy" in the USA context, Hurd provided "a new label for the well-established notion that some mastery of science is essential preparation for modern life" (Feinstein, 2011, p.168). This spurred efforts in their respective parts of the world to boost science literacy in society. Hurd's original use of *literacy* concerned school education (DeBoer, 2000). But Shen (1975, p.48) extended it to the education of wider society by introducing the terms *practical science literacy*, as "the possession of the kind of scientific knowledge that can be used to help solve practical problems", *civic science literacy*, which would enable citizens to "[bring] their common sense to bear upon such issues and thus participate more fully in the democratic processes of an increasingly technological society", and *cultural science literacy*, "motivated by a desire to know something about science as a major human achievement". More generally, the OECD defined science literacy (sometimes known as scientific literacy) as "the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (Gilbert, 2004, p.40).

Independently of the exact definition adopted by various science-literacy advocates, the rhetoric was that knowing basic but important facts of science would directly improve people's lives. Further, it was argued that the more a society were familiar with scientific facts and the scientific method, the greater would be the support it would show for the financial costs associated with research (Paisley, 1998). Therefore, scientific research and its fruits needed to be disseminated as widely as possible to bridge a perceived gap in the general public's knowledge (Bauer and Falade, 2014; Gregory and Miller, 1998). Advocates of improving science literacy called upon scientists and science communicators to fill a perceived *knowledge deficit* among the public by sharing the outcomes of scientific research with wider society. It was presumed that such a society with greater science literacy would not only be aware of science's pervasiveness in day-to-day affairs, it would also champion the cause of science, reduce opposition to research endeavours and tackle social conflict regarding science (Nisbet and Scheufele, 2009, p.1767). This model of science communication had "a vertical social and epistemological hierarchy with science at the top" (Gregory and Miller, 1998, p.1255). It was this drive for communication with the goal of boosting science literacy that influenced science policy in the West at least into the 1980s (Sturgis and Allum, 2004). How science literacy was interpreted also evolved over time, "moving from the ability to read and comprehend science-related articles to its present emphasis on understanding and applying scientific principles to everyday life" (Burns, O'Connor and Stocklmayer, 2003, p.187).

In 1985, a related phrase – "public understanding of science" or PUS – entered the discourse. Although the term had been in use in the USA along with science literacy since the 1960s (Shen, 1975), the publication of a Royal Society report in the UK chaired by Dr Bodmer (and therefore sometimes known as the Bodmer Report), signalled the emergence of a new paradigm in the interplay between science and society (Bauer and Falade, 2014). The Bodmer Report concluded that it is "part of each scientist's professional responsibility to promote the public understanding of science" (Royal Society, 1985, p.34). What followed was "a wave of funding for and interest in public communication" (Davies, 2008, p.413). According to Stocklmayer and Bryant (2012), the use of the term gained further traction only a few years later following a paper by Durant, Evans and Thomas (1989) published in *Nature*.

Where science literacy addressed a deficit of knowledge, PUS concerned itself with an *attitudinal deficit*, worrying that society was "not sufficiently positive about science and technology, sceptical or even out-right anti-science" (Bauer and Falade, 2014, p.148). Gregory and Lock (2008, p.1254) contend that scientists believed that "public disinterest in, and negative attitudes towards, science had weakened science's political influence and so undermined its claim on government funds". It was argued that familiarity with science, rather than breeding contempt, would foster a greater appreciation for it.

If science communication seeks to shift society's knowledge of or attitudes towards science, such a shift would need to be measured following the establishment of a baseline. The first survey to measure society's science literacy dates back to 1957 in the USA, before Sputnik and prior to Hurd's popularisation of the term (Bauer and Falade, 2014); such surveys were soon adopted in Europe and subsequently in other parts of the world. They initially took the form of quiz-like statements designed to determine the respondent's grasp of scientific facts, which were used as a proxy to measure the scientific literacy of society at large (Bauer and Falade, 2014; Stocklmayer and Bryant, 2012; Sturgis and Allum, 2004). However, despite years of attempting to boost science literacy, including using the PUS approach, the data from surveys conducted in Europe and the USA showed that science-literacy levels as of the late 1990s had remained "depressingly low" (Sturgis and Allum, 2004, p.56) and largely unchanged from surveys conducted in previous decades (Miller, 2001, p.115). Later surveys to measure PUS adopted Likert-type attitude items framed as statements with numerical values assigned to an *Agree–Disagree* scale. Through these, researchers found that "while knowledgeable members of the public are more favourably disposed towards science in general, they are less supportive of morally contentious areas of research than are those who are less knowledgeable" (Evans and Durant, 1995, p.57).

Questions were raised about what exactly the science-literacy surveys were measuring. The futility of the surveys was demonstrated by Stocklmayer and Bryant (2012, p.18), who showed that scientists themselves did not perform very well when expected to recount scientific facts from memory: "The scientists themselves are deeply divided on this issue. Many recognise, in their own inability to be certain of their answers, that the public cannot be expected to retain facts that are not useful." The uncertainty associated with many of the questions that make up standard science-literacy surveys proved challenging to overcome for experts in that particular field: "if you know 'too much' you are beset by uncertainty and your scores suffer" Stocklmayer and Bryant (2012, p.13).

The underlying assumptions about a knowledge deficit or an attitudinal deficit came to be known as the "deficit model". This model of science communication was criticised for "the weak empirical foundations of its assumptions and the limited results achieved by the communicative actions it has inspired" (Bucchi and Trench, 2014, p.4). Bauer (2009, p.224) noted that "one is not literate or illiterate, but more or less knowledgeable". Further, those facts that were relevant to an individual's life or experiences – sometimes called "knowledge-in-context" – would be valued more highly than more esoteric facts (Bauer and Falade, 2014; Stocklmayer and Bryant, 2012; Sturgis and Allum, 2004). Nisbet and Scheufele (2009, p.1767) state: "Many of these initiatives start with the false premise that deficits in public knowledge are the central culprit driving societal conflict over science, when in fact, science literacy has only a limited role in shaping public perceptions and decisions." It was acknowledged that people in general only care about specific scientific facts in as much as they pertain to their daily lives. For example, people are more likely to care about a medical condition if they or their relatives suffer from it (Feinstein, 2011, p.177). Therefore, the ability to remember and recount facts of science does not adequately represent society's interest in science as a whole, nor would it allow them to engage with social and civic issues around science.

Science-communication research has since accepted the inadequacy of relying exclusively on the notion of a knowledge deficit when communicating with non-specialists. While the research does not deny the *existence* of a knowledge deficit among those with differing levels of education on specialised topics, it notes that treating non-specialists members of wider society as merely vessels to be filled is problematic in itself. There has been an acknowledgement that non-experts, including members of lay society, can play a valuable role in making scientific progress. As Miller (2001, p.117) commented, this approach "sees the generation of new public knowledge about science much more as a dialogue in which, while scientists may have scientific facts at their disposal, the members of the public concerned have local knowledge and an understanding of, and personal interest in, the problems to be solved". Rather than attempting to fill a knowledge deficit by sharing facts, this paradigm seeks to engage with society, and has come to be known as "public engagement with science" (Felt *et al.*, 2007; Horst and Michael, 2011; Horst, 2013; Michael, 2012).

2.2 Public engagement with science and technology

The deficit model was characterised by one-way communication, *from* science *to* society (Trench, 2006). The role of the non-scientist in the interaction was to take in the information provided and apply it to their lives as prescribed. But as the deficit approach was criticised for its weak foundations and its ineffective approach, society turned its attention to the prejudices held by scientific experts towards non-experts (Bauer and Falade, 2014, p.150). The bovine spongiform encephalopathy (BSE) crisis in the UK in the 1990s and the controversies surrounding genetically modified organisms (GMO) shone the spotlight on a *trust deficit* between wider society and scientific experts (Irwin, 2001; Millstone and van Zwanenberg, 2001; Wynne, 2006). Drawing from his work with sheep farmers in the UK and their response to scientific experts advising them on the radiation fallout from the Chernobyl incident, Wynne (1992) was one of the first to call for greater dialogue with those holding relevant but unrecognised expertise. Calls for dialogue saw the relationship begin to be viewed not as "science *and* society" as two distinct entities but as "science *in* society", in which the practice of science is embedded in a sociocultural setting and in which science should be seen as responding to the needs and values of society (Trench, 2006). By the mid-2000s, a report commissioned by the European Commission (Felt *et al.*, 2007, p.55) found that, "The PUS 'paradigm of science dissemination' has been partially translated into what could be termed a 'paradigm of dialogue and participation' or Public Engagement with Science (PES)." Bauer and Jensen (2011, p.3) argue that "the term public engagement has taken the specific meaning of communicative action, to establish a dialogue between science and various publics".

Public engagement (nowadays abbreviated to PEST with the inclusion of "technology") advocates for the involvement of society in some form in the research enterprise (Felt *et al.*, 2007; Horst and Michael, 2011; Horst, 2013; Michael, 2009). However, the extent to which this involvement is possible will necessarily vary depending on the research domain in question. The PEST paradigm had a basis in democratic ideology: that, for example, in societies where tax funds are allocated for scientific research, the citizens should have a say in how those funds are spent, and also that they should be able to speak personally with the scientists in receipt of the funding (Wilkinson and Weitkamp, 2016). It resulted in "a wave of consensus conferences, deliberative forums, and town meetings on a number of issues" in Western countries in the first decade of the millennium (Nisbet and Scheufele, 2009, p.1768).

The establishment of the PEST paradigm was accompanied by sociologists arguing that the use of the term "the general public" as a catch-all for non-specialists across all of society sought to unfairly generalise across diverse and distinct groups. Society is in fact composed of several self-identifying groups, based on their own senses of identity and group belonging, and can include educators, policy makers, professional bodies, members of industry as well as representatives of civil society. Instead, the term "*publics*" came to be used, which "has been associated with the proposal of a contextual model of communication, according to which the communicators inform themselves about, and are attentive to, the various understandings, beliefs and attitudes within the public" (Bucchi and Trench, 2014, p.6). This transition from a monolithic *general public* to the diversity of *many publics* has been crucial to the evolution of science communication as a research field (Davies, 2008; Michael, 2009; Wilkinson and Weitkamp, 2013; Wynne, 2007). Similarly, the use of the term *lay society* was singled out as ignoring the many non-traditional expertises that non-scientists have, which can either play a role in research itself or can be affected by the latest progresses of society (Collins and Evans, 2007; Wynne, 2003). However, this term still serves a useful purpose in distinguishing – for the sake of simplicity – between those with expert knowledge in a specific scientific domain and those who do not possess the same level of expertise. Indeed, scientists are themselves non-experts outside of the contexts of their own research and interests, as a biologist may be when it comes to geology or electronics engineering (Schäfer, 2012). At the same time, some scholars make the point that acknowledging the domain-specific expertises of so-called "lay persons" does not in any way detract from the expertises of those researchers who have invested years of study into their fields (Collins and Evans, 2007; Collins, 2014). What *has* been argued is that through the interaction with various publics, public engagement has the power to shape research by making the scientists think about their own research in new ways through interactions with diverse groups.

Two of the many forms of PEST are deliberation and participation. Deliberation – or consultation – can take the form of public debates on specific scientific projects (e.g. Hagendijk and Irwin, 2006) or on "their very purpose and motivations" (Owen, Macnaghten and Stilgoe, 2012, p.754). In 2003, the UK government sought public deliberation under the *GM Nation?* banner into plans to commercialise genetically modified (GM) foods and introduce them into the market (Rowe *et al.*, 2008). Although well-meaning, the national debate drew criticism for, among other things, the structure of the debates themselves and the lack of transparency on the side of those advocating for GM crops. But the main criticism had to do with when it was introduced: "it took place too late to influence the direction of GM research, or to alter the institutional commitments of the biotechnology industry and other key players" (Wilsdon and Willis, 2004, p.37). The resulting hostility of society to the plans, not just in the UK but elsewhere in Europe, were partly attributed to the late – or "downstream" – engagement with society on the issue: the product was ready for the market and the role of the debate was to perfunctorily stamp the existing plans. Although downstream engagement is not flawed in and of itself in all contexts, it was argued that early, "upstream" engagement was crucial, particularly in areas where the science carries a real or perceived risk. Learning from the failures of the GM debate, European governments and researchers sought to employ upstream engagement with societal deliberations on nanotechnology (Wilsdon and Willis, 2004, p.38).

Participation is what Bucchi and Trench (2014, p.6) call a three-way mode of communication, contrasting it with the one-way deficit mode and the two-way dialogue mode "because it implies publics or citizens talking with each other as well as talking back to science and its institutions". Participation goes a step beyond deliberation by allowing interested members of society to play a role in research itself. It can take the form, for example, of working together with representative groups to identify what questions *need* to be asked in the first place. Nicklin *et al.* (2010) provide a compelling example of this kind of upstream participation: patient research partners played a role in supporting all decisions taken in three studies regarding people with rheumatoid arthritis. Previous studies on the matter had not worked with patient groups prior to the research and had thus missed that fatigue was a big part of what those with the condition experience. Upstream participation can therefore be thought of as collaboration.

Citizen science is also sometimes included within the umbrella of participatory engagement (e.g. Dickinson *et al.*, 2012; Shirk *et al.*, 2012). They have however been criticised for being driven by deficit approaches and "[aiming] to increase participants' knowledge about science and the scientific process, and to change their attitudes toward science" (Brossard, Lewenstein and Bonney, 2005, p.1101). Despite this, they offer *a* pathway to participation in the research enterprise, and Collins and Evans (2017, pp.137–138) divide citizen science into two types. The first involves what is frequently referred to as "crowdsourcing for science" (Wiggins and Crowston, 2014), with examples including Galaxy Zoo,[*] in which volunteers look for novel features in photos of space, and LHC@home,[†] in which volunteers donate computer time to perform calculations that are used for particle-physics research. The latter crosses the lowest bar for participation – indeed one could argue it is not participation at all – with volunteers merely having to install software on their computers that would allow calculations to be performed when the device was not being used by the volunteer. Crowdsourcing is thus a type of downstream citizen science, in which participants have no voice in designing the research project but may play a role in collecting and analysing data. On the other hand, upstream citizen science may see citizen groups formulate their own research questions and may seek involvement from scientists in order to pursue their own objectives and empower their communities. Here, research is done not just "by

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[*] https://www.zooniverse.org/projects/zookeeper/galaxy-zoo/
[†] https://cern.ch/lhcathome/

the people" but "for the people" (Collins and Evans, 2017, p.138). Figure 2.1 shows the four different combinations of deliberation/participation and upstream/downstream engagement. One of the aspects of this doctoral research is to determine the validity of deliberative and participatory approaches to public engagement in particle physics.

Upstream deliberation (e.g. nanotechnology)	Downstream deliberation (e.g. "GM Nation?")
Upstream participation "collaboration"	Downstream participation "crowdsourcing"

Figure 2.1: Quadrants of engagement

It is important to remark here that while there is a tendency to think of the three paradigms – literacy, understanding and engagement – as neatly succeeding one another, the reality is that the three have considerable overlap in practice depending on the context (e.g. Davies, 2013). Indeed, while charting the transition of the paradigms into three stages:

1. "… scientists were encouraged to inform the public…"
2. "… scientists were encouraged to develop dialogue on scientific facts and processes…"
3. "…scientists must engage with society in the early phase of scientific development…"

Crettaz von Roten (2011, p.54) reminds us that the "three discourses are not mutually exclusive".

2.3 Science communication in context

There are two important factors to consider when discussing the context(s) in which science-communication research is performed and presented. One is the geographic, linguistic and cultural representation within wider scholarship, while the second concerns the domains of science that are the focus of social-in-society research. Both contexts are particularly important for this research project given that (a) despite being based in Europe, CERN has scientists from around a hundred countries representing all inhabited continents and (b) as will be made evident below, very little science-communication literature exists on fundamental research such as particle physics.

Regarding geographic representation, Guenther and Joubert (2017, p.4) note that despite positive trends in greater geographic diversity within mainstream English-language scholarship, the field is dominated by "research contributions from Western, English-speaking countries". They do acknowledge that science-communication research can be found in languages other than English as well as in English-language journals with a national or regional focus. Nevertheless, both these types of seemingly fringe but invaluable scholarship tend to get ignored by publications in the three main (English-language) journals in the field. Indeed, it is important to acknowledge that this very literature review has a bias towards works published by authors who not only have English as a first or main language but who most often analyse science communication in Western Europe and the USA. On the linguistic and cultural front, Irwin (2014, p.74) implores us to "be aware of the different meanings that can be attributed to PES[T]" in non-Western settings. For example, Bucchi and Trench (2014, p.3) remind us that the term *popularisation* has "the longest tradition among those used to describe a wide range of practices in making scientific information accessible to general, non-expert audiences". Despite this term having fallen out of fashion in Western scholarship and policy, they note that it continues to be used in countries like China to describe activities that might, in English, be referred to by terms associated with some of the later paradigms that emerged. Indeed, within Latin-origin languages, the equivalent terms could be *vulgarisation* (French) or *divulgación* (Spanish). The introduction into supposedly global scholarship of newer paradigms that emerge from the socio-political policies of a handful of national governments will not necessarily affect the persistence – in some parts of the world – of words and terminology that would be considered *passé* among the dominant scholars. A related problem is the increasing use of jargon in science-in-society scholarship. Having performed a textual analysis of research published in the journal *Public Understanding of Science*, Baram-Tsabari *et al.* (2020, p.644) found:

> "Readability decreased and use of jargon increased between 1999 and 2000 and the two following decades for empirical and non-empirical papers, and all parts including the abstracts. An analysis of rare words shows that most are not part of the general academic vocabulary or disciplinary jargon, but rather words that appeared only in one article. *Public Understanding of Science* has moved away from everyday language. This does not mean it is incomprehensible to its scholarly readership, but may have consequences to other audiences

such as practitioners."

Note that even as simple a term in English as "engagement" cannot be trivially translated to other languages, resulting in the many coded meanings that it carries being lost in other contexts, particularly if they're also meant to be picked up and internalised by scientists and not just by science-communication scholars.

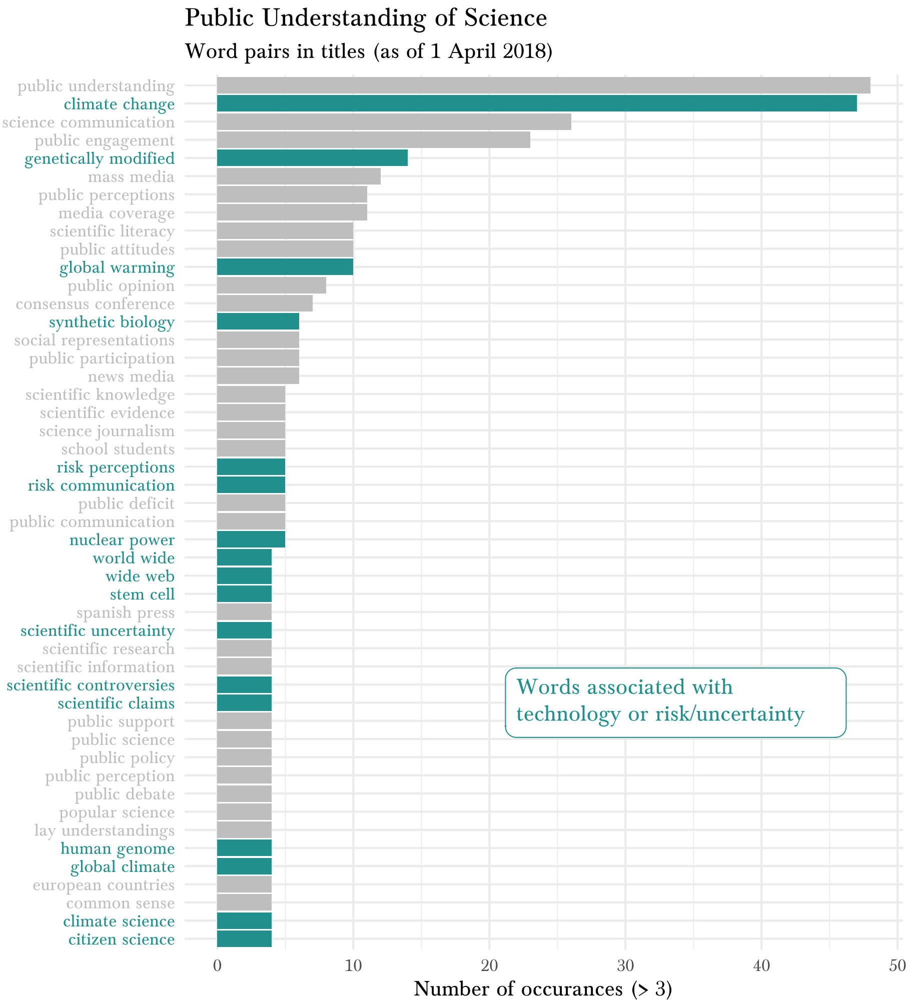

Figure 2.2: Word pairs occurring at least 4 times in paper titles in Public Understanding of Science

The second of the two contexts concerns the fields of scientific research that are represented in science-communication scholarship. Besley *et al.* (2021) recently found that less than 10% of articles published in five science-communication-related journals concerned basic science. This is not entirely surprising. Most scholarship in the field tends to focus on matters of risk and uncertainty rather than science per se (e.g. Felt *et al.*, 2007; Frewer, Scholderer and Bredahl, 2003; Hornig, 1990; Miller, 1999; Wynne, 2007). Figures 2.2 and 2.3 show the prevalence of certain words associated with technology or risk/uncertainty in the titles of the last 1000 papers published in the journal *Public Understanding of Science* as of 1 April 2018. In particular, most examples of participatory approaches to public engagement cited in the literature address research fields with an impact on human life: these include biomedical research, environmental sciences, genomics and technology, to name a few (e.g. Bruni, Laupacis and Martin, 2008; Cook, Pieri and Robbins, 2004; Delgado, Lein Kjølberg and Wickson, 2011; Dickinson *et al.*, 2012; Felt and Fochler, 2008; MORI, 2000; Rowe *et al.*, 2005; Shirk *et al.*, 2012; Wilkinson, Dawson and Bultitude, 2012; Wynne, 2007). The *Taking European Knowledge Society Seriously* report (Felt *et al.*, 2007) concerns itself with nanotechnology, medical sciences, neuroscience and genomics. Physics, chemistry and geology are missing almost entirely from the discourse. Fundamental sciences, and subjects like particle physics in particular, face challenges associated with communicating research practices and outcomes that are unlike those experienced by fields with more practical consequences, but are rarely discussed in scholarship.

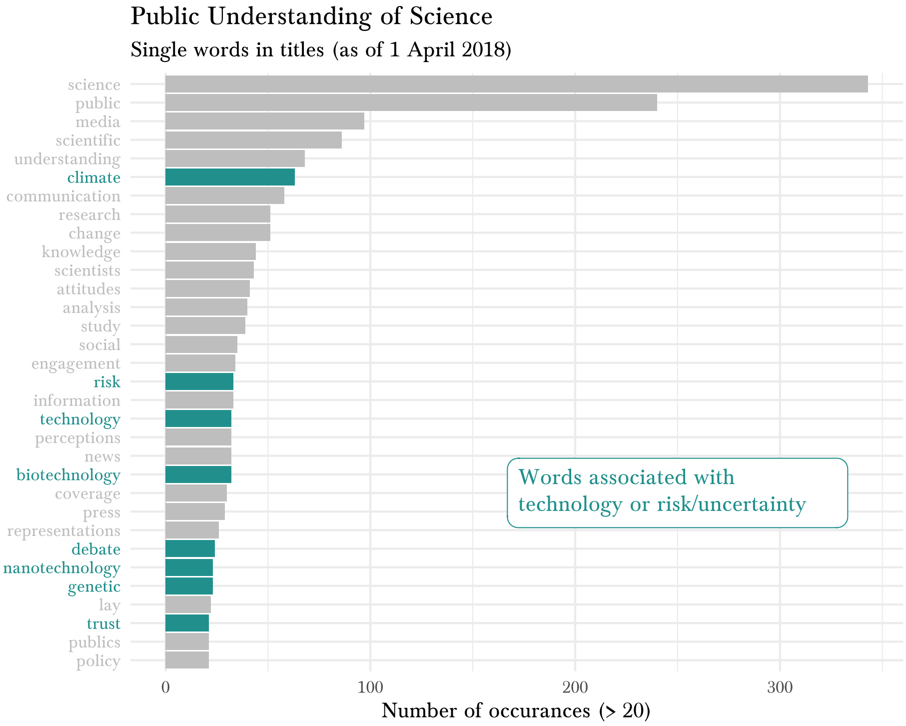

Figure 2.3: Words occurring at least 21 times in paper titles in Public Understanding of Science

This narrow focus is also reflected in efforts to study the attitudes of society towards a variety of fields of research. For example, a survey conducted in the UK sought to ascertain the participants' awareness of these particular topics: "climate change, vaccination of people against diseases, human rights, renewable energy, the use of animals in research, the way the economy works, medical ethics, nuclear power, research into human behaviour, genetically modified plants (GM crops), ensuring the UK has enough food, stem cells research, clinical trials, radioactive waste, nanotechnology, synthetic biology" (Ipsos MORI, 2011, p.32). The survey did not address a single field of fundamental research. There appears to be, when looking at the body of literature on public engagement with research, a lack of consideration of fundamental research, areas which are less likely to have an explicit impact on human life, despite, as Schäfer (2012) points out, these areas receiving extensive coverage by science-communication outlets. The lack of focus on fundamental research in other scholarly work on the relationship between science and society highlights a gap in our understanding of public attitudes toward fields of fundamental research as well as of the possibilities of engagement with society. As Dudo and Besley (2016) showed, physicists prioritise conveying a sense of wonder in their science-communication efforts, and there is evidence that members of lay society are keen to participate in volunteer-computing-based citizen-science initiatives (Nov, Arazy and Anderson, 2014; Vinsen and Thilker, 2013). Therefore, it seems that the potential for public engagement in the true sense may need to be carefully evaluated in fields of research that are under-represented in science-communication scholarship.

2.4 Reflections on public engagement

Besides the limited contexts in which PEST research and scholarship is carried out, it also suffers from the lack of a well-established definition, making it challenging to evaluate public-engagement activities. One of the conclusions of the Royal Society, Research Councils UK and Wellcome Trust (2006, p.6) study was indeed to define public engagement. Individuals and organisations have certainly tried since then, but the definitions always seem to focus on applications or risk; for example, Scheufele *et al.* (2021) define it in relation to “the development of new technologies”. Indeed, Reed *et al.* (2018, p.145) note that there exists “a normative assumption within this definition that public engagement should produce benefits for the economy or society”. Given that the myriad meanings and interpretations suit the scientists, allowing them to chose activities that they are most aligned with, it may be impossible to find a universally agreed-upon definition. Reed *et al.* (2018) therefore propose that it is good practice that is standardised for the purpose of evaluation of public engagement.

The participatory basis of public engagement have been questioned in recent years (Braun and Schultz, 2009). In their book *Participation: The New Tyranny?*, which deals with participatory democracy beyond just PEST, Cooke and Kothari (2001, p.8) note that “participatory ideals are often operationally constrained by institutional contexts that require formal and informal bureaucratic goals to be met”. Public participation also requires “significant resources need to be spent on sampling, recruitment and turnout” (Nisbet and Scheufele, 2009, p.1774). In some instances, the overly broad definition of public participation leaves, as Rowe and Frewer (2005, p.254) argue, "room for variable interpretation, because the public may be involved (in policy formation, etc.) in a number of different ways or at a number of levels". Irwin (2006, p.300) warns of the orthodoxy of the defence of public participation, speculating that "that uncritical treatment of current science–public interactions might lead to an equally uncritical backlash when policy expectations of public consensus and support are (almost inevitably) disappointed". He goes on to note that PEST is itself mired in a deficit model of its own:

> "[O]ne can detect that the old language of cognitive deficit increasingly is in competition with talk of a new form of deficit: this time a deficit not of scientific understanding but of public trust. Just as top-down communication was seen as the cure for the old deficit, greater openness and consultation can remedy the new one (even if the 'new' style characteristically represents a very top-down commitment to the bottom-up [. . .])." (Irwin, 2006, p.303)

Irwin (2014, p.73) also comments that " 'deficits' are fundamental to many forms of communication and as such can never be discarded". Similarly, Bucchi and Trench (2014, p.5) note that in some forms of science communication – such as those taking place science cafés – there is no expectation of participation and "the satisfaction for those involved may reside in the exchange itself rather than anything beyond it".

2.5 Attitudes towards public engagement

So far we have considered the attitude of society towards science through various lenses, but what about the attitude of scientists towards the public and public engagement? Psychologists define *attitude* as "an evaluation of an object of thought", and as something that can be applied to "things, people, groups and ideas" (Bohner and Dickel, 2011, p.392). Keeping this in mind, we can consider the attitudes that scientists have towards public engagement through the examination of a variety of potential attitude objects, such as the perceived benefits of public engagement, groups of people that they prioritise for their communication efforts and even the sentiment that public-engagement activities evoke in them. The views of scientists towards public engagement and the level of their involvement have not been studied in much depth; Bauer and Jensen (2011, p.8) provide a critical overview of the limited literature available and note that "it remains unclear to what extent [public engagement] remains a personal choice, or has become a normative part of the [organisational] culture of research institutes and laboratories across Europe".

Surveys of scientists in the UK have found that most participate in some form of public engagement, reflecting positive views of the experience, with the number who report to doing so growing over time. A survey by MORI (2000) found that 56% of scientists had participated in at least one communication activity in the previous year, with the number rising to 74% a few years later (Royal Society, Research Councils UK and Wellcome Trust, 2006), with Hamlyn *et al.* (2015) reporting 78% of scientists in their survey having done so. However, in the USA, Ecklund, James and Lincoln (2012) – who interviewed 97 scientists working in physics, astronomy and biology – found that only 58% were involved in some form of public engagement.

Across the surveys in the UK, most scientists feel a sense of duty to publicly communicate their research, which Poliakoff and Webb (2007) included under "moral norms" in their study of scientists at the University of Manchester. Poliakoff and Webb (2007) found that the scientists in general viewed public engagement positively. In Spain, Martín-Sempere, Garzón-García and Rey-Rocha (2008) found that most of the scientists responding to their survey at a public-engagement event in Madrid were fairly or highly motivated to increase the public's enthusiasm for science, with most reporting being motivated by a sense of duty.

We can also understand the attitudes of scientists to public engagement through the benefits that they perceive to be derived from their participation. These benefits could be to society more generally, or to the scientists themselves. Nearly half the responses to the MORI (2000) study mentioned better understanding of science being a benefit in itself. Other responses included the fact that greater understanding would allow the public to judge science issues for themselves and to make informed decisions about their own lives. However, when asked how participating in public communication benefited themselves, 14% of the scientists reported seeing no benefit of the sort. However, the positive responses included the belief that public communication helps with their research, attracts funding, gives them a sense of enjoyment, advances the role of science and gives them experience in communicating. The Royal Society, Research Councils UK and Wellcome Trust (2006) study also found that the biggest incentive for participating in outreach was bringing more money into the department.

Conversely, scientists may perceive barriers that prevent them from being more involved with public engagement. Besides a lack of time (e.g. Royal Society, Research Councils UK and Wellcome Trust, 2006), a frequently cited barrier was the perception that their colleagues would not approve of their participating in public engagement (e.g. Hamlyn *et al.*, 2015, p.36; Ecklund, James and Lincoln, 2012, p.4). This "perception that popular, visible scientists are worse academics than those scientists who do not engage in public discourse" (Martinez-Conde, 2016, p.2077) is known as the Sagan effect, named after astronomer Carl Sagan, who was a prolific scientist in addition to being a popular science communicator. Although it might dissuade some from public engagement, studies have shown that the Sagan effect itself may not be real: researchers participating in public engagement may in fact perform better on certain academic metrics than their non-participating colleagues (Jensen *et al.*, 2008). Several of the scientists in MORI (2000) study noted that scientists themselves lack the communication skills and interest to participate in public communication of their research.

A greater number, however, described to the public's own lack of knowledge about scientific facts as a barrier: 53% of the responses of the mentioned this concern. Similarly, society's lack of understanding about the scientific process and their lack of interest in research were listed as barriers, and the media were also blamed. The attitudes towards the public, generally speaking, seem to be dominated by deficit-style thinking. Research showed that "75% of Spanish scientists think that the general public has a serious lack of knowledge and understanding of scientific reasoning" (Llorente *et al.*, 2019, p.1). More than half of the respondents also believed that Spanish society is uninterested in supporting public investment in science and technology, with a third believing that public investment is prioritised for applied science over basic science. The MORI (2000, p.10) study also found that scientists in the UK "have a far more favourable image of themselves than they think the public has of them".

On the other hand, compared with other groups, the scientists frequently rated the general public (albeit in their capacity as "tax payers") as the most important group to communicate their research with, only topped by peers and fellow scientists in frequency (MORI, 2000). They also voted the media as most important least frequently. The Royal Society, Research Councils UK and Wellcome Trust (2006) study also found scientists assigning low ratings to general journalists (i.e. those who don't cover science as their main beat). The low rating given to journalists would seem to indicate that scientists prefer to communicate their work directly instead of relying on vectors to do so. Indeed, as the MORI (2000) study showed, even in instances where the scientists engaged with the media, they rated their own communication efforts as more effective than when they relied on the journalists. Nevertheless, Peters (2013) shows that most scientists in different fields and different countries report having interacted at least once with a member of the media in the previous three years, and many report mostly positive interactions with them. In terms of disseminating their work, Wilkinson and Weitkamp (2013) found that environmental researchers in Europe tended to prefer traditional media coverage over social media, while Hamlyn *et al.* (2015) found that this varies by age, with younger researchers more likely to communicate about research on social media. Curiously, Liang *et al.* (2014, p.772) has shown that "being mentioned on Twitter amplifies the effect of interactions with journalists and other non-scientists".

Scientists may think of public engagement as serving different purposes. Indeed, the Royal Society, Research Councils UK and Wellcome Trust (2006) study noted that the term itself is ambiguous and open to interpretation. It also reported concerns that "many scientists see the main reason for engaging with the public as the need to 'educate' them rather than to debate, listen and learn as part of a genuine dialogue" (Royal Society, Research Councils UK and Wellcome Trust, 2006, p.14). This can perhaps be seen as an extension of the lecture hall into the public sphere; Ecklund, James and Lincoln (2012) found that a third of the scientists they interviewed in the USA were involved with science-communication activities involving school-aged children.

Attitudes towards public engagement may also be influenced by factors such as one's gender, job type and career stage, with senior researchers viewing it more positively; for example, Martín-Sempere, Garzón-García and Rey-Rocha (2008) showed that senior researchers in Spain were most highly motivated by a sense of duty. On the other hand, Andrews *et al.* (2005) reported that graduate students at a particular USA university were more motivated by the opportunity to improve their communication and teaching skills, compared with faculty members. The role of gender does not appear to be straightforward though: in the USA, Ecklund, James and Lincoln (2012, p.4) note that "women are much more involved in outreach than men", which they suggest may be because of "the perception that outreach is a more feminine, care-oriented task", while Crettaz von Roten (2011, p.52) notes that in Switzerland, "attitudes toward public outreach and engagement activities are the same among men and women scientists, but that activities are done significantly more often by men scientists than by women scientists", attributing this partially to the fact that "media contact women scientists less often than men scientists". Among other influencing factors, Poliakoff and Webb (2007, p.259) found that "scientists who decide not to participate in public engagement activities do so because [...] they have not participated in the past".

Funding agencies play a key role in translating the latest science-communication theories into practice, and their requirements for public engagement may change how scientists perceive it. Palmer and Schibeci (2014, p.512) remark that funding bodies "are in a position to potentially influence science practice and PES[T] specifically, if this is a desired outcome of research funding". If funders establish it as a norm, it would make it difficult to hide behind the Sagan effect as a barrier. They found that while funding bodies supported professional communication within the research community, support for “engagement with the broader community is variable” (Palmer and Schibeci, 2014, p.511). That is, while funding agencies may have introduced mandatory participation in science-communication activities, the nature of these activities continue to fall on a spectrum from *dissemination* to *engagement*. For example, they note that “the emphasis is squarely on nationwide deficit-style strategies” (Palmer and Schibeci, 2014, p.517) in some countries (e.g. USA, China), despite a cultural shift towards a participatory paradigm in others (e.g. UK).

The MORI (2000) study showed that there are differences in how UK scientists across a range of disciplines perceive audiences, with differences between biomedical and non-biomedical researchers especially pronounced. The study found that scientists whose work carried no social or ethical implications [such as certain fundamental sciences] were more likely to see increased public understanding as a benefit in itself. On the other hand, clinical researchers were more likely to focus on the social and ethical aspects of their work (Royal Society, Research Councils UK and Wellcome Trust, 2006). Johnson, Ecklund and Lincoln (2014, p.91) found that “Cultures of disciplines may influence cultures of outreach,” noting that in the case of physics in the USA, outreach is “culturally peripheral” and not “a core component of work”. However, where the scientists *did* participate in public engagement, Dudo and Besley (2016, p.9) found, also in the USA, that “physicists and astronomers were more likely to say they [prioritise] communication designed to excite public audiences”.

2.6 Particle physics and outreach

Understanding how public engagement is embodied in a community requires a more general understanding of the community’s practices and beliefs. Although it is now three decades old, the book *Beamtimes and Lifetimes: The World of High Energy Physicists* by Traweek (1992) provides an insightful ethnography of the particle-physics community, relying on fieldwork conducted at SLAC and Fermilab in the USA and at KEK in Japan, with the author also visiting DESY in Germany and CERN. Traweek (1992, p.126) finds that the community is “firmly committed to the international, supracultural image of science” with the scientists seeing themselves as having “more in common with each other than their next-door [neighbours]”. The culture is characterised as one of extreme objectivity, which Traweek (1992, p.162) describes as “a culture of no culture”. Among other factors, the the costs associated with constructing the machines required to pursue particle-physics research have led to ever larger research collaborations, situated at a handful of dedicated laboratories located primarily in North America, Europe and East Asia. These collaborations are “international, overlapping networks of exchange that hold the community together[, . . .] bound together by a way of thinking, about the world and about knowledge and about themselves” (Traweek, 1992, p.xi).

The preferred term to refer to public engagement within the particle-physics community is “outreach”. This is reflected in the names of organisations such as the International Particle Physics Outreach Group (IPPOG), a collaboration of scientists, science educators and communications specialists who share best practices and participate in joint public-communication projects, with a focus on formal and informal education (IPPOG Collaboration, 2020). The term is also mentioned in the original _European Strategy for Particle Physics__ (CERN Council, 2006) and was used as a synonym for public engagement in a report on the 2013 strategy update, under the section on the wider impact of particle physics (emphasis added):

> “Many groups work enthusiastically in *public engagement*. They are assisted by a network of communication professionals (EPPCN) and an international outreach group (IPPOG). *Outreach and communication in particle physics* should receive adequate funding and be recognised as a central component of the scientific activity.” (Radford *et al.*, 2013, p.22)

Therefore, it is appropriate to use the term “outreach” in this context to refer to all science-communication activities “designed for an audience outside academia” (Crettaz von Roten, 2011, p.54), since this term is used among particle physicists across the globe to encompass a variety of science-communication activities ranging from working with schools to direct dialogue with the public to disseminating information through the media. This approach is supported by Crettaz von Roten (2011, p.54), who states: “It is [. . .] better to use a more general term that can include activities resulting from the three discourses [information, dialogue and engagement]. [. . . T]hese approaches can be used together for scientific development or by any given scientist, and we make no normative distinction between their advantages and disadvantages.”

In addition to the multi-party organisations coordinating wider public engagement, many of the particle-physics laboratories around the world also engage their local community in a variety of ways. For example, Fermilab has a Community Advisory Board,* that was set up in response to calls from neighbouring counties to have a greater say in on-site construction and civil-engineering works due to their effects on the locals (Kunz, 2010; Yurkewicz, 2004). CERN’s community engagement does

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*https://www.fermilabcommunity.org/

not involve the local community in either France or Switzerland in the same way in decision-making, although any works to be undertaken need to be approved by the local authorities, sometimes involving public voting on the matter. Indeed, CERN's very establishment in Geneva had to be voted on at a public referendum in the Canton of Geneva in 1953.[*]

Communication with the local communities also takes the form of addressing societal concerns about environmental consequences of the research infrastructure. In 1997, the Brookhaven National Laboratory in the USA found that tritium – a radioactive isotope of hydrogen – had been leaking from the laboratory into the ground water resulting in concentrations twice as high as allowed by federal drinking-water standards. An investigation followed that showed the leaks had been occurring for at least 12 years, unbeknownst to the authorities (United States General Accounting Office, 1997). Measures taken since then have ensured that particle-physics laboratories have the means to monitor such leaks early. For example, Fermilab maintains a web page with information on the levels of tritium that can be found in surrounding water bodies (Fermilab, no date), which have always been well below the federally mandated critical levels. While CERN had been publishing internal reports regarding its environmental impact, the laboratory also started publishing public environment reports since 2019 (CERN, 2019).

Although environmental risks may be low, there are reputation risks to particle physics itself, such as when the USA government cancelled the proposed Superconducting Super Collider (SSC) in 1993. The cancellation of the accelerator – which would have been the world's biggest and most powerful, dwarfing the potential of CERN's LHC – showed that "support for a scientific [programme] depends less on its own merits than on public attention and understanding" (Paisley, 1998, pp.71–72). With this experience in mind, CERN began a concentrated communications effort to build excitement around the LHC before it began operations, highlighting its potential for discovery and the value of pursuing basic science (Chalmers, 2018). The efforts paid off, with the LHC's switching on receiving positive coverage worldwide.

CERN's institutional communication efforts often highlight the transfer of knowledge and technology from particle physics to wider society. The role of particle physics in advancing medical imaging technologies and treatments, and the economic impact to industry as a result of collaborating with CERN are frequently cited (e.g. CERN, 2020). The World Wide Web was also invented by Tim Berners-Lee while at the laboratory, and CERN is keen to draw attention to the economic benefits of

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[*] https://timeline.web.cern.ch/where-build

its decision to release the web openly and freely for the world to use (Gillies and Cailliau, 2000). The rhetoric of societal benefits appears to well-founded. Purely on financial returns, research into the costs and benefits of the LHC between 1993 and its originally scheduled decommissioning in 2025 provided a conservative estimate that "there is around a 90% probability that benefits exceed costs, with an expected net present value of about 2.9 billion euro, not considering the unpredictable applications of scientific discovery" (Florio, Forte and Sirtori, 2016, p.38). Further, the sentiment among CERN's member states is generally positive. A recent "willingness to pay" survey in France showed that a slim majority of French taxpayers were willing to pay more taxes to support CERN's research (Florio and Giffoni, 2020, p.1): "The estimated willingness to pay is higher than the current implicit per capita tax burden of French citizens." This chapter started with the role that was played by physics in transforming society in the mid-twentieth century; communication of particle physics by CERN continues to emphasise that transformative role to this day.

Chapter 3

Research methods

The research design chosen for any endeavour must be suitable to provide meaningful answers to its research questions. This chapter provides an overview of the epistemological underpinnings governing the design adopted for this doctoral research and details of its implementation. It concludes with an expression of hope that the procedures described herein follow, and indeed contribute to, the principles of open science.

3.1 A pragmatist worldview

Creswell (2009) describes ontologies and epistemologies using the term "worldview" – what others such as Morgan (2007) call "paradigms" – and enumerates four kinds of it. The *postpositivist* worldview takes a reductionist approach, seeking to ascertain the nature of cause and effect experimentally. Under the *participatory* worldview, the research being undertaken cannot be separated from politics, seeking political change through advocacy as an outcome of the research. *Social-constructivism* focuses on subjective meanings and seeks to build upon the experiences and perspectives of the research participants through qualitative data, acknowledging the role of historical and cultural norms in shaping the perspectives. Finally, *pragmatism* concerns itself with applications and solutions, focusing on the research problem at hand rather than the specific methods to be used, and encourages the researcher to use all suitable avenues to address the problem.

Of these, it is self-evident that the experimental approach championed by postpositivism to probe long-term cause–effect relationships is unsuitable for this research, as is the participatory paradigm because the research does not seek to undertake political or change-orientated advocacy. Although social-constructivism provides appropriate tools – such as personal interviews and case studies – for exploring the research questions of this project in considerable depth, it would not allow for a broad, global description of the field of particle physics.

Consequently, the pragmatist paradigm was chosen to address the research questions. In her overview, Feilzer (2010, p.8) notes that pragmatism "orients itself towards solving practical problems". In this regard, pragmatism is well suited for this particular area of study. For instance, science communication itself is a practical field with professionals around the world engaged in some form of it, ranging from scientists themselves to science journalists. Therefore the outcomes of any research into science communication carry the potential to mould its practice. In addition to being shaped by such academic discourse, the practical elements of the field are also influenced by ever-changing societal expectations. Gathering data on attitudes of scientists towards science communication – and contextualising and interpreting them - can address practical problems in the vocational sphere of science communication itself.

3.1.1 Using mixed methods

Mixed methods is a well-regarded strategy of inquiry under pragmatism: "inquirers draw liberally from both quantitative and qualitative assumptions when they engage in their research" (Creswell, 2009, p.10). According to Feilzer (2010, p.8), this allows the researcher to use "quantitative methods to measure some aspects of the phenomenon in question and qualitative methods for others". An advantage is that mixed methods "can accommodate scientific [rigour] and theory alongside uncertainty and instability" (Evans, Coon and Ume, 2011, p.277). The specific procedure employed for the research described in this thesis relied on "sequential mixed methods" (Creswell, 2009), in which the findings of one method can be elaborated by the second.

Depending on the research objectives, sequential mixed methods may be performed in either order. In the case of research into the attitudes of scientists towards outreach, much of the literature relies on surveys as a main – and sometimes only – source of data (see § 2.5). Therefore, although this research project did not seek to replicate previous results, performing a quantitative analysis of survey data first would nonetheless provide a basis for a broad exploration of the attitudes towards outreach in particle physics and allow one to compare the findings with wider scholarship. The subsequently performed qualitative analysis would then enable a deeper understanding of these attitudes and of factors that are unique to particle physics – such as the role played by being part of a large, international collaboration.

Accordingly, the data collection was divided into two complementary and sequential phases: quantitative data from a survey were collected first (see § 3.3), followed by the collection of qualitative data from personal interviews (see § 3.5) with the aim of seeking convergence between the two. The quantitative-data collection gathered a broad range of views concerning the scientists' attitudes to outreach and potential influencing factors, to identify patterns in these and assess their relative strengths across various sub-groups of scientists (§ 3.4). A preliminary analysis of these data then served as the basis for the structure of the qualitative-data collection, for a more in-depth exploration of any questions of interest, particularly concerning the science-in-society paradigms that hold sway (or co-exist) in particle physics (§ 3.6). However, some of the questions in the interviews were not connected to the survey data, and indeed not all aspects of the survey data were explored in the interviews: Table 3.1 shows which data sources were used to address each of the four research questions. The results of the analyses described below (see Chapters 4 and 5 respectively) are synthesised together in Chapter 6.

Table 3.1: Research questions and data sources used to answer them

RQ1	"What are the attitudes towards outreach within the particle-physics community, including the motivations for – and barriers against – participating in outreach activities?"	Survey	Interviews
RQ2	"Do these attitudes towards outreach within the particle-physics community vary with respect to age, gender and outreach experience?"	Survey	
RQ3	"How, if at all, are these attitudes influenced by (a) differing expectations from funding bodies and (b) being part of large, international collaborations?"	Survey	Interviews
RQ4	"Are participatory paradigms present in the discourse concerning outreach within the particle-physics community, and what is the perceived relevance of the research to the everyday lives of non-specialists?"		Interviews

3.2 Target population

The target population for this research is the global community of researchers involved in high-energy particle-physics. The size of this population is not straightforward to determine. As the world's largest laboratory for particle physics, CERN hosts researchers from all over the world, who are not employed by CERN but who use the research facilities at the laboratory. In 2015, CERN estimated that – with some 12,000 visiting scientists from across the globe – approximately half of all particle physicists worldwide come to CERN for their research (CERN, 2015).

Another approach to calculate the population size is to calculate the number of unique authors in the field. Fortunately, the particle-physics community has maintained a database of literature going back to the 1970s. Known as INSPIRE[*] today, the online database is maintained in collaboration by particle-physics laboratories and institutes from around the world: CERN, DESY (Germany), Fermilab (USA), IHEP (China), IN2P3 (France) and SLAC (USA). Following a request made to the INSPIRE team for an estimate of the number of unique authors on the database between 2014 and 2018 (inclusive), one of the team members provided the numbers by personal correspondence (Moskovic, 2019). There were an annual average of 37,872 authors in the five years in question. Moskovic was careful to note that the number of authors on INSPIRE were only an estimate and do not necessarily represent unique authors because of errors with double-counting same authors. The INSPIRE estimate brings the approximate proportion of particle physicists conducting their work at CERN closer to 32% of the global community.

Nevertheless, taking these two estimates into consideration, we can conclude that somewhere between a third and a half of all particle physicists perform their research at CERN, making it a suitable site for data collection for this research.

Besley and Nisbet (2013, p.12) “use the term ‘scientist’ as encompassing a broad array of individuals from across science-, medical- and engineering-related fields, working in research and non-research positions, holding varied levels of post-graduate degrees, and employed across the university, government, non-governmental or industry sectors”. This research adopts a similar approach, and the term “scientist” in the context of particle physics is defined more broadly and includes physicists (those with PhDs as well as doctoral students), engineers and non-doctoral students working in research as well as non-research positions.

3.2.1 The study population

As mentioned in the thesis introduction (Chapter 1), the study population – a subset of the target population – is the CMS Collaboration at CERN. Specifically, it includes all scientists (as defined above) who are part of this collaboration. Named after the Compact Muon Solenoid detector at the Large Hadron Collider, CMS is an international collaboration of researchers from around 200 institutes and universities from over 40 countries. The collaboration has built and now operates the CMS detector, collecting and analysing collision data from the LHC to investigate the laws governing particle physics. CMS is one of two general-purpose detectors at the LHC, the other being ATLAS. Both collaborations are some of the largest ever assembled, with research papers published by each authored by over 2000

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[*] https://inspirehep.net/

contributors, a sizeable proportion of the global particle-physics community.

At the time that the survey was disseminated, the internal CMS database (see details below in § 3.3.2.2) listed a total of 5098 personnel, with 4751 qualifying as "scientists". A breakdown of the different kinds of scientists in CMS is available under Table 3.2, where "Physicist" includes 9 theoretical physicists. This is the size of the study population for this research.

Table 3.2: Proportions of sub-groups within final sample for quantitative analysis

Scientist type/role	N	%
Physicist	1930	40.62%
Engineer	960	20.21%
Doctoral Student	956	20.12%
Non-Doctoral Student	905	19.05%

Note:
CMS total as of 2 July 2015

3.3 Collecting survey data

Since this research builds upon previous work regarding attitudes towards public engagement with science, many of which have relied upon surveys, a survey approach was chosen to allow comparability with prior studies. Examples of related research were studied to identify relevant questions which could be used for such a comparison. The questions used in the survey were based on the following four works:

- *The Role of Scientists in Public Debate* (MORI, 2000),
- *Survey of Factors Affecting Science Communication by Scientists and Engineers* (Royal Society, Research Councils UK and Wellcome Trust, 2006),
- *What Factors Predict Scientists' Intentions to Participate in outreach of Science Activities?* (Poliakoff and Webb, 2007) and
- *A Case Study in Serendipity: Environmental Researchers Use of Traditional and Social Media for Dissemination* (Wilkinson and Weitkamp, 2013).

Select survey questions from these were mapped to the four research questions and modified to make them not only uniform but also suitable for this study. Some of the open-ended questions were transformed into Likert-type statements (see § 3.4.2). For example, questions in the above studies concerning potential target groups for communication required the respondents to select all groups they considered relevant to their work; the introduction of scales allowed respondents of this survey to rate these audiences on specific parameters. Likert-type statements from the baseline studies had the associated numerical scale reduced from 7 to 5 to keep all ratings in this study consistent. Where previous surveys contained no existing questions that suitably addressed particular research topics of this project, new questions were prepared.

The survey language was English: although it is not the first language of all CMS members, it is the working language for formal communication within the collaboration and therefore a suitable language for this research.

3.3.1 Piloting the survey

Prior to the start of quantitative-data collection, the initial draft of the survey was piloted with a small group of participants, with three objectives (PO):

- **PO1**: Test whether the survey could address the research questions and to determine how long it would take to respond to the entire survey.
- **PO2**: Assess whether the language employed in the survey was clear and understandable to a diverse group of respondents, many of whom speak English as a second or additional language. At the time of quantitative-data collection, there were over 80 nationalities represented in the CMS collaboration, speaking a variety of languages as their primary tongue. It was therefore critical that the pilot phase identify any phrases used in the survey that might pose linguistic barriers for some CMS members: as Bethlehem (2009, p.45) warns, “The question text must use words that are familiar to those who have to answer them.”
- **PO3**: To determine whether differing outreach mandates among funding agencies around the world are reflected in differing attitudes towards outreach amongst their respective scientists.

Scientists working at CERN but not affiliated with the CMS collaboration were approached to participate in the survey, including some from ATLAS, CMS’s sister collaboration at the LHC (§ 3.3.1.1). Since it would have proved impossible to sample every one of the many linguistic groups within CMS to test the word choices in the survey, citizens from three countries were targeted: the United States of America (USA), the Russian Federation (Russia) and the People’s Republic of China (China). These countries were not chosen because they were particularly representative of the nationality make-up of

CMS: indeed as of June 2015, the number of CMS members who are citizens of these countries (taking into account the only nationality recorded in the internal database in cases of those with multiple nationalities) was 887, 379 and 171 respectively. Instead, the choice was made to increase the chances that the pilot would provide perspectives from not-closely-related cultural and linguistic groups. Prior to contacting potential participants for the pilot study, a target of 30 responses was set, equally divided between the three aforementioned countries.

3.3.1.1 Soliciting pilot participants

Potential respondents to the pilot survey were contacted via two avenues:

1. The ATLAS "survey contacts" mailing list.

   The aforementioned ATLAS collaboration conveniently maintains a mailing list of collaboration members who have agreed to participate in surveys. While contacting such a group of people implicitly acknowledges their self-selection biases (Bethlehem, 2010) – after all, they volunteered to be part of a list aimed exclusively at responding to surveys – this was the first, most-logical possibility to explore. Accordingly, I contacted one of the two ATLAS outreach coordinators at the time with my request, which was then forwarded to the list. As a result of this e-mail, four USA citizens volunteered to participate in the pilot survey. (A fifth USA citizen was contacted directly about participating in the pilot, having expressed their interest in the research earlier.) No responses were received from Russian and Chinese citizens, although it is unknown whether there were any on the list to begin with.

2. The CERN mailing lists for Russian and Chinese "Users"

   An alternative approach was therefore taken to involve Russian and Chinese participants. As previously mentioned, the vast majority of people working *at* CERN do not work *for* CERN: they are "Users" of CERN's facilities and not members of CERN Staff. CERN maintains separate mailing lists of CERN Users by nationality. I contacted the CERN Staff member responsible for access to these lists and was subsequently granted mailing privileges on the Russian and Chinese lists. After writing to these lists and sending two reminders to each, nine responses were received from Russian citizens and four from Chinese nationals.

Thus, a total of 18 people agreed to participate in the pilot phase of the quantitative-data collection, which was lower than the number originally sought.

3.3.1.2 Running the pilot survey

Rather than have the respondents fill in a survey in their own time, data were collected during one-on-one sessions with individual participants, allowing for greater interactivity between researcher and participant. The one-on-one sessions took place in person when possible and using the "Vidyo" video-conferencing tool when participants were not located at CERN. Participants were provided with copies of the information sheet and asked to sign the consent form prior to being given the survey questionnaire. In instances where the participants were located remotely, they uploaded scanned copies of the consent form to a secure directory on CERN's self-hosted OwnCloud instance, called CERNbox. The survey itself was conducted on paper. In-person participants filled the survey on their own, while giving feedback on the questions to the researcher as they went along. Remote participants had an electronic copy of the survey in front of them and the researcher recorded their answers on paper, along with notes based on their feedback. The participants were asked to provide feedback about the survey both while they were filling it in as well as on completion. Particular focus was made on unclear words or phrases and on any difficulties they had in interpreting a question.

After 14 participants had responded to the pilot survey, the survey's questions and structure were revisited to take into account the feedback received. The survey was subsequently refined before the final four participants (Russia: three; China: one) were involved. The final survey was prepared based on the feedback received across the two phases of piloting and a preliminary analysis of the data collected from them.

3.3.1.3 Survey pilot: outcomes

- **PO1**: Preliminary analysis of the data from the pilot showed that the research questions were indeed addressed by the survey. Changes were made to the content of the survey and to the order of the questions, with questions of a similar type grouped together and the superfluous ones or those that did not provide meaningful data (as shown in the preliminary analysis) removed. Each pilot participant took around 30 minutes filling in the survey; however, this included interruptions that arose during the process.

- **PO2**: The biggest issue raised by the pilot concerned the use of the term "outreach". This term was used in the survey without any definition or explanation and proved to be problematic for some of the respondents from Russia and China. In particular, they sought clarification on whether the term referred to education, media relations, popularisation and/or propaganda. To minimise confusion, the final survey included a note at the start explicitly defining it: *"The term 'outreach' refers to all science communication and education activities that bring scientific research to audiences outside the research community. It is also known as 'popularisation'."* The second sentence is particularly important because the term "popularisation", which was once commonly invoked in Western English-speaking countries in the context of science communication, has fallen into relative disuse there; nonetheless it has remained in use in other parts of the world, including in countries where English is not spoken as a primary language after being borrowed from the English language.

- **PO3**: The sample size of the pilot survey was too small to draw conclusions about whether the final survey would show differences in attitudes towards outreach based on the mandates of various funding agencies. Nonetheless, based on the responses and feedback received during the pilot phase, the questions addressing this matter were retained and refined.

3.3.2 The final survey

The final survey was of the *computer-assisted web interviewing (CAWI)* type (Bethlehem, 2009, p.3); that is, an electronic survey was hosted on the web and circulated to the study population by e-mail. It is crucial to note that this approach has the disadvantage of being influenced by self-selection biases (Bethlehem, 2010).

Following the pilot phase, the survey questions and sections were finalised and uploaded to the SharePoint service hosted at CERN, accessible as a web form available at a dedicated URL. Access to the website containing the survey was restricted to members of the CMS collaboration (i.e. the study population): every potential respondent had to authenticate themselves using the CERN Single Sign-On system, and only those with permissions saw the survey. Others with CERN credentials but without an affiliation to the CMS collaboration were denied access to the page.

The username of each respondent was recorded along with their responses, allowing the relevant auxiliary data to be retrieved from the CMS internal database. Only the researcher had access to the responses. The landing page of the website contained the information sheet as well as the consent form, and respondents had to select the option to give their consent before being shown the survey. The information sheet informed the survey participants how their responses would be used. The participants were also informed that while their responses were confidential, they were not anonymous:

their usernames would be recorded during the process and subsequently mapped to their auxiliary data.

Questions were grouped thematically and structured in a linear order, without any randomisation: all respondents saw the same questions in the same order. The survey was broken down into discrete web pages containing specific questions. In some instances, pages were skipped when the questions they contained were rendered non-applicable based on responses to previous questions. A copy of the final version of the implemented survey can be found in Appendix A.

3.3.2.1 Soliciting survey participants

As mentioned before, soliciting responses to a web-based survey has certain limitations, including self-selection biases. Nonetheless, it was the optimal way to gather quantitative data from a large-enough sample from the CMS collaboration, most of whom are not based at CERN.

Since the research was partially supported by CMS, the collaboration's management agreed to the dissemination of the survey to all CMS members via an internal mailing list. Unfortunately, the initial plan - to announce the survey to the entire collaboration during the opening plenary session of a CMS-wide conference taking place at CERN – fell through. The survey was therefore announced to CMS members at a much-lower-profile meeting: that of the CMS Collaboration Board in early 2015.

Following the announcement at this meeting, a first e-mail was circulated to the entire CMS collaboration, with the permission of the CMS management. Over the course of the data-collection period, regular reminders were sent to the same mailing list soliciting responses to the survey. Each e-mail triggered a flurry of responses, which died down after a few days. A final e-mail was sent on the last nominal day of data collection.

A total of 374 unique responses had been received by the end of that day. However, the overall representation from engineers was low despite them making up a large portion of the CMS collaboration. It was decided to target this demographic of the collaboration for a separate call for survey responses. This was done by writing to a mailing list of all registered engineers in the CMS collaboration. The wording of the e-mail was modified from the original batch of e-mails, specifically inviting the engineers to fill in the survey. This effort only brought in ten new unique responses and one duplicate, bringing the total number of valid responses from engineers to 36, although this represents a 38% increase from the pre-targeting numbers. One speculates that the engineers on CMS may not have felt addressed by the call out to CMS scientists. Indeed most public-engagement endeavours within CMS tend to focus on physics rather than on engineering.

A preliminary analysis of the data gathered at this point showed that some of the CMS member countries[*] were underrepresented. It was therefore decided, in a similar vein to the targeting done for engineers, to solicit responses from the following seven countries with low response rates: (1) China, (2) Taiwan, (3) Switzerland, (4) South Korea, (5) Russia, (6) Lithuania and (7) Turkey.

E-mails were sent out to the funding-body representatives from these countries, requesting them to circulate a reminder to their colleagues. This approach was largely unsuccessful, yielding only seven new responses in total. Having exhausted all avenues of collecting quantitative data, this phase of data collection was declared closed shortly before the end of the year. The country-wise distribution of the final (valid) responses is shown in Table 3.3).

Table 3.3: Responses received by country

Country	Responses	Response rate
US	115	8%
Italy	42	8%
Germany	25	7%
Belgium	23	16%
UK	23	16%
CERN	22	8%
France	20	11%
India	14	10%
Spain	13	14%
Finland	9	11%
Russia	9	3%
Austria	8	14%
Brazil	8	12%
Switzerland	8	9%
China	6	8%
South Korea	5	5%
Greece	4	9%
Hungary	4	10%
Turkey	4	4%
Taiwan	4	7%
Bulgaria	3	10%
Mexico	3	11%
Pakistan	3	7%
Poland	3	7%
Portugal	3	11%
Lithuania	2	2%
Malaysia	2	10%
Thailand	2	22%
Cyprus	1	6%
Egypt	1	2%
Croatia	1	5%
New Zealand	1	7%

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[*] Henceforth in this thesis, the term "country" applies not to the nationality of the respondents but to the nation in which their institute or university is based. So, an Indian working for a university in the UK would fall under "UK". Note, also, that CERN – being located in both Switzerland and France – is recorded separately from either country.

3.3.2.2 Personnel data from the CMS internal database

It was clear from the beginning that some of the information about each survey participant – such as their name, age, gender, (primary) nationality, academic affiliation, and scientist type – could be retrieved from a regularly updated internal database of all CMS members. Collecting these ***auxiliary variables*** (see details under § 3.4.1) separately from the survey would result in a shorter survey for the participants as they would not have to provide their personal details. Further, it was assumed that this would also minimise errors in data entry in the survey. Unfortunately, as was identified later, there were a few errors in the database itself since these data were entered into it manually.

Authorisation was sought from the CMS management as well as the CERN Legal Service prior to making a request to access this CMS internal database and make secure copies of it regularly (see § 3.7). Subsequently, the systems administrator responsible for the CMS database gave the researcher access (via CERN Single Sign-on) to an online XML file containing the information on all CMS members shown in Table 3.4.

Table 3.4: Information collected from the CMS internal database

Information	Notes
Last Name(s)	
First Name(s)	
Primary nationality	
Title	"Dr."/"Prof." or not [Not used]
Gender	Male/Female binary from official identity documents
Birthdate [YYYY-MM format]	[Not used]
Age	
CMS role	Scientist type: physicist, engineer etc.
Percent of time spent at CERN	[Not used]
CERN ID	[Not used]
Institute of affiliation	Used to obtain country of affiliation

During the initial two months of the survey being live, a snapshot of the XML file was made once a week: on Monday morning. This was to ensure that information would be available about new collaboration members or those who may have left the collaboration after responding to the survey. In anticipation of the final reminder being circulated, snapshots were also taken on 26 June 2015 and 2 July 2015.

3.3.2.3 The survey dataset

The full database of responses was periodically downloaded with appropriate timestamps while the survey was live. This was because participants had the possibility of returning to their responses and deleting them, which was one of the quirks of the way data-entry permission could be given to the authenticated members of CMS. However, no deletions were recorded while the survey was accessible to CMS members, at the end of which there were 403 responses recorded.

The survey responses and the relevant *auxiliary variables* from the CMS internal database had to be combined manually. In the process, a few issues were revealed.

Firstly, there were 11 duplicate responses in total. These duplicates were not caused by data duplication but by respondents participating in the survey twice, which was identified courtesy of the fact that potential respondents to the survey had to authenticate themselves using the CERN Single Sign-On. Some of the CMS members who had already filled in the survey following one of the previous e-mails acted on subsequent ones as well. The first instance of each duplicate response was used for the final analysis. However, rather than discarding the second instances of data entry by the same person, they were used as a means to test whether responses were internally consistent. For all the Likert-type variables, the 11 duplicate responses were compared with the first instance of data entry by the same person (see § C.1). The responses remained largely the same, with a few votes changing by 1 in either direction and very few changing by 2. Importantly, there were no major swings in the voting patterns. These accidental re-submissions, then, present valuable data in themselves. Since the respondents had perhaps forgotten that they had filled the survey once before, they did not necessarily recall their previous responses. Therefore, the fact that the answers given at both times were largely the same is encouraging.

Secondly, at least two of the *auxiliary variables* retrieved from the CMS internal database had errors in them: an Austrian scientist known to the researcher was assigned the nationality "Australian", while another respondent's age was incorrectly recorded as 105. It is therefore possible that some of the other auxiliary variables have inaccuracies in them due to human error at the time of data entry in the original CMS database. However, it is impossible to estimate the error rate, and we have to assume the personal data collected through these means are largely accurate.

A preliminary descriptive treatment of the data also showed that two of the responses to the question "Have you ever participated in an outreach activity?" did not have an answer, although the respondents did list the number and frequency of outreach activities they had participated in during the preceding 12 months. Therefore, both responses were assigned the value "Yes" for this question by the researcher. No other data were manually altered.

One of the respondents did not seem particularly satisfied with their personal situation when it came to outreach. They chose to express their dissatisfaction by responding with a rating of 1 for all questions bar one (which received a rating of 3). In the free-text-entry section at the very end of the survey, this respondent stated their displeasure by pointing out that in a particular country only the big institutes received support from their funding bodies for doing outreach, claiming that this was discrimination. Since their responses to the survey seemed like a protest vote with no meaningful data to be gathered from them – indeed, there were no similar responses in the entire dataset – this respondent's data were removed from the final dataset.

This left a total of **391 valid responses** in the survey dataset.

3.3.3 Survey timeline

The relevant dates for the survey data collection are as follows:

- 13 February 2015: Survey announced to CMS Collaboration Board
- 17 February 2015: E-mail circulated to all CMS members with link to survey, soliciting responses
- 27 February 2015: First reminder sent via e-mail to all CMS members
- 11 March 2015: Second reminder sent via e-mail to all CMS members
- 26 June 2015: CMS Collaboration Board chairperson reminds Collaboration Board members about the survey, who also received a reminder via e-mail
- 3 July 2015: Final reminder sent via e-mail to all CMS members; survey closed at end of day
- 23 September 2015: Reminders sent to engineers
- 4 November 2015: Representatives of underrepresented countries contacted
- 30 November 2015: Survey formally closed

3.4 Quantitative analysis

The methods described below, particularly the use of exploratory factor analysis (§ 3.4.3) come from the domain of psychometrics and studies there are conducted differently, with control groups for example, which this research project did not have. It is worth reiterating that the data do not necessarily describe a true underlying reality, but are shaped by both the researcher's choices and the survey respondents' self-perception. Indeed, the mixed-methods approach relies on synthesising narratives from quantitative and qualitative analyses.

All of the quantitative analysis in this thesis was done using R version 4.2.1 (R Core Team, 2022).

Most of the data analysis and data visualisation relied upon the `tidyverse` meta package (Wickham *et al.*, 2019), especially `ggplot2` for the visualisations. The `likert` package (Bryer, 2019) was used to present the visualisation of Likert-type data, while other packages used for the data visualisations include `patchwork` (Pedersen, 2020) and `viridis` (Garnier *et al.*, 2021). The tables were made using `knitr` (Xie, 2021b), `kableExtra` (Zhu, 2021) and `stargazer` (Hlavac, 2018).

3.4.1 Types of variables

In specifying the *variables* that should be measured by a survey, Bethlehem (2009, p.16) distinguishes between *target variables* and *auxiliary variables*, stating that the former "measure characteristics of the elements that contribute to answering [the] general survey questions". The *target variables* in this survey addressed the following aspects of the project's objectives:

- the perceived benefits of outreach participation;
- general attitudes towards outreach, including motivations and barriers for outreach participation;
- the degree to which respondents are satisfied with the outreach requirements of their research funders; and
- the groups that the scientists prioritise for their communication activities.

The questions that made up the survey were selected to address the *target variables*, and comprised mostly ratings-based questions (such as Likert scales, which are described below in Section 3.4.2). *Auxiliary variables* include information such as the respondent's age, gender, academic position and institutional affiliation, which were collected using the CMS internal database, and information such as outreach experience of the respondents and their awareness of their funders' outreach requirements, which were collected from the survey.

3.4.2 Using Likert scales to measure sentiment

In 1932, as part of his doctoral research, psychologist Rensis Likert developed the well-known ordinal scale that bears his name (Likert, 1932) and which is used extensively by psychologists, epidemiologists and other social scientists to measure attitudes and sentiments of specific groups towards particular topics: "to understand the views of residents concerning various social issues, to predict the values of consumers, or to assess the political views of constituents" (Willits, Theodori and Luloff, 2016, p.129). The scale allows respondents to "choose from a range of possible responses to a specific question or statement" typically from "strongly agree" to "strongly disagree" (Jamieson, 2004). The scales traditionally tend to have 5 or 7 items, although some researchers adopt a scale with an even number of items despite the fact that it "forces subjects to omit the item or provide an incorrect response" (Willits, Theodori and Luloff, 2016, p.134).

The ratings usually go from low to high: "the negative pole on the left and the positive one on the right" (Hartley, 2014, p.84). As an ordinal scale, the ratings on the scale are categorical and not numerical; that is, even when we assign numbers to represent each value on the scale (e.g. 1 for "strongly disagree" and 5 for "strongly agree"), the numbers represent the order or directionality of categorising the responses but do not indicate equal intervals between each rating. It is therefore encouraged that Likert data generally be analysed with non-parametric statistical techniques rather than using parametric tests that assume, for example, a normal distribution of the data (Jamieson, 2004). However, Jamieson (2004) notes that researchers nevertheless describe Likert data using means and standard deviations or by performing tests such as ANOVA.

On the other hand, Sullivan and Artino (2013, p.542) conclude that several statistics experts support the use of parametric tests on ordinal data, but they "recommend that authors determine how they will describe and [analyse] their data as a first step in planning educational or research projects". Indeed, Hartley (2014) states that large sample sizes lend support for parametric tests with Willits, Theodori and Luloff (2016, p.135) arguing that such tests "maintain their essential validity even when their assumptions (normality, homogeneity of variances, sample size and interval measurement) are not strictly met".

It is worth remarking on the difference between individual "Likert-type" statements and aggregate Likert scales that combine several related Likert items. It is inadvisable to use individual items on their own for statistical treatment: "the underlying phenomenon of interest, say satisfaction with teaching, [is] being measured by an individual's responses to the entire set of items" Harpe (2015, p.839).

In this research, individual statements concerning attitudes towards outreach are shown in plots mapping the relative agreement/disagreement. They are explicitly combined to form a scale only in the case of groups targeted for communication (§ 4.2.3).

3.4.3 Exploratory factor analysis

It is crucial that one not fall pray to reductionism when mathematising data in the social sciences, particularly from surveys. Nevertheless, we can derive insight by statistically analysing the survey data from this research using exploratory factor analysis (EFA), a widely used technique in social sciences.

EFA relies on the idea that “unobservable phenomena underlie observed measurements” (Watkins, 2021, p.1). Specifically, it assumes that “the observed variables reflect linear combinations of underlying factors” (Ferguson and Cox, 1993, p.84). However, EFA remains “a complex procedure with few absolute guidelines and many options” (Costello and Osborne, 2005, p.1). Various methods have been proposed for calculating the number of factors, but none has particular merit over the others. Scholars have suggested that empirical methods be complemented by the researcher’s domain knowledge in order to strike a balance between comprehensiveness and parsimony (Watkins, 2021).

The survey data that used Likert-type statements were grouped into three categories: (1) benefits of outreach participation, (2) general perceptions about outreach and (3) “favourability” of groups for communication. First, the data were checked to determine their suitability for factor analysis: the Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy was calculated; Bartlett’s test of sphericity was used to check for significant correlation in the data; and Cronbach’s α was calculated, based on 50 iterations. Since all three categories were determined to be suitable for factor analysis, the “parallel analysis” technique was used to ascertain the number of factors in each of these categories of variables (Watkins, 2021, p.77) using the “unweighted least squares” method with the “promax” oblique method (Costello and Osborne, 2005, pp.2–3). Because the first two categories had ordinal data, the polychoric correlation matrix was used for the parallel analysis (Watkins, 2021, p.115), while the latter used a continuous scale created by combining the three individual Likert scores for each group of people and so relied on the Pearson correlation matrix. The EFA was used to reclassify the variables in all three categories, following which generalised linear regressions were carried out with the independent variables of age, gender, outreach experience and outreach requirement from funders.

The EFA was performed with R using the and `psych` package (Revelle, 2021), along with `parameters` (Lüdecke *et al.*, 2020), while the regressions were carried out using the built-in `stats` package (R Core Team, 2022).

3.5 Collecting interview data

Qualitative analysis has proliferated in recent years, reaching new fields of research, developing new methods and approaches for data analysis, and concerning itself with new types of data (Flick, 2014, p.4). This research, however, used interviews, a more traditional type of data, with the aim of describing the attitudes towards outreach within the particle-physics community focusing on the analysis of the content of the interviews.

The interview phase of this research was performed after the survey data had been collected and a preliminary analysis performed on them to identify areas for greater exploration. The questions selected for the interviewees (which can be found in Appendix B) were drafted specifically to address the following aspects of the research questions of this thesis:

- the conceptualisation of "public engagement",
- the relationship between society and particle physics,
- the relationship between funding and outreach,
- the influence of international collaboration on attitudes towards outreach, and
- perceptions about the communication of particle physics.

3.5.1 Piloting the interviews

Prior to soliciting interviews from members of the CMS collaboration, the questions were piloted on three scientists from outside CMS; they worked on the ATLAS collaboration at CERN. All three were known to the researcher to be active in outreach at CERN. Of the three, two were affiliated two North American institutions and one was affiliated to a European one; two were senior researcher and one was a young researcher; and two were men and one was a woman.

The scientists were contacted by e-mail to request their participation in the research project, and all three agreed. All interviews were conducted in person at CERN, in English. The interviewees were first provided with an information sheet and a consent form. A dedicated recording device was then used to record the interviews. Follow-up questions, not in the original questionnaire, were asked where it was found that answers could be explored further. The interviews were then transcribed by the researcher and cursory coding was performed, which showed that the responses addressed the areas of the research questions as described above. However, some of the questions had their wording adjusted slightly.

3.5.2 The final interviews

The strategy of "purposive sampling" was adopted for this research, in order to explore the aforementioned aspects of the research questions, and the target sample size was 20 "information-rich" scientists. It was decided that the majority of the interviewees would be those *with* outreach experience (according to their survey responses) as well as those in senior positions in the CMS collaboration. Consequently, most of the scientists initially contacted to be interviewed were either known to the researcher to be active in outreach or held key management roles within the collaboration, and it was ensured that there was representation from countries in Europe, North America and Asia. Interviews were sought from both physicists and engineers, and – in order to explore relationships that the survey could not address – those from countries that were underrepresented in the survey were also contacted. The latter group was mostly comprised of scientists in the CMS internal database (§ 3.3.2.2) who had *not* responded to the survey.

In total, 37 scientists were contacted personally by e-mail. Of these, 18 responded, and of those who responded interviews could be arranged with 16. All 16 interviewees had participated in the survey phase and no replies were received from those had not participated in the preceding survey. The interviews were conducted between 17 November 2016 and 22 September 2017: five during an off-site collaboration-wide meeting in Mumbai (India), ten at CERN and one over a video call.

The interviews were all in English and followed an identical procedure to the pilot interviews. The scientists at the in-person interviews were given the information sheet and consent form to sign, following which the interviews were recorded on a dedicated device or on the researcher's cellphone. The participant in the video-based interview was provided with the information sheet and the consent form electronically, and they uploaded the signed document to a secure shared directory on CERN's in-house cloud service; audio and video from this interview was recorded using the built-in recording features of the video-conference platform (Vidyo) and subsequently downloaded for storage with the other recordings.

The number of interviews from CMS was lower than foreseen. However, in conjunction with the three pilot interviews, it was established that data saturation was achieved (Grady, 1998; as cited by Saunders *et al.*, 2018) and further interviews were not sought. Inclusion of the pilot interviews in the final qualitative dataset was deemed appropriate due to following key factors. Firstly, the questions had remained mostly unchanged between the pilot phase and the final interviews. Secondly, the interviews were conducted following the same procedures in both cases, including getting the scientists' consent to use the interviews for this research. Thirdly, participating in the interviews was not contingent on participating in the survey beforehand. And finally but most importantly, the three scientists were from the ATLAS collaboration, which runs CMS's sibling general-purpose detector – ATLAS – at the LHC; the two collaborations are similar in size, have researchers regularly moving from one collaboration to the other, pursue the same physics research, collaborate on a variety of outreach activities at CERN and have even published a joint research paper with a combined 5154 authors (ATLAS Collaboration and CMS Collaboration, 2015).

Taking these into account, the three pilot interviews from ATLAS scientists were combined with the 16 interviews from CMS scientists to give a final dataset of **19 interviews** for qualitative analysis.

3.6 Qualitative analysis

As "a method for identifying, analysing and reporting patterns (themes) within data" (Braun and Clarke, 2006, p.79), thematic analysis is ideally suited for the qualitative analysis of this mixed-methods research. It has been described as a flexible tool that can provide a rich account of data and identify themes that "[captures] something important about the data in relation to the research question, and represents some level of patterned response or meaning within the data set" (Braun and Clarke, 2006, p.82). The authors warn, however, that is is crucial to make one's assumptions explicit when using this method. In the case of this research, because the interview questions were designed to explore specific aspects of the attitudes of scientists towards public engagement, it was assumed beforehand that the themes identified would be coupled – loosely or rightly – to the aspects; this indeed proved to be the case. Another limitation to be aware of is that thematic analysis benefits from two or more researchers performing the coding and comparing them, which is not possible in the case of doctoral research done by an individual.

The thematic analysis was performed in accordance with the steps delineated by Braun and Clarke (2006). First, all the interviews were transcribed.[*] To save time, this was done by a professional transcriptionist affiliated with UWE Bristol, whose services were paid by the university using the budget allocated for this research. Unfortunately, the transcriptionist's unfamiliarity with both the vocabulary used in particle physics (including names of particles and of research laboratories) and the myriad accents of the interviewees resulted in several errors in the documents. This meant that I had to examine all of the transcripts to compare them with the recordings and rectify the mistakes before beginning the formal analysis. However, this gave me the opportunity to familiarise myself with the corpus as a whole, an important step in thematic analysis.

The cross-checked transcripts were systematically coded – using the free and open-source application,

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[*] One of the audio files was corrupted before transcription and ended abruptly, resulting in a small loss of material from that interview.

QualCoder (Curtain, 2021) – to identify particular features in the interviews. Each of the 19 interviews was examined separately, with key words and phases highlighted and codes assigned. Among others, the codes included “the Higgs boson”, “culture”, “create empathy”, “recruit”, “provide funds/taxes”, “educate”, “outwards facing”.

Once all of the interviews had been coded, the codes were grouped into broad themes and sub-themes using QualCoder’s built-in categorisation tool, generating a rudimentary thematic map, which included:

- general topics that were mentioned (e.g. the Higgs boson, the LHC, technology transfer, the World Wide Web, culture),
- what the interviewees saw as the purpose of outreach (e.g. create empathy, convey enthusiasm, inspire, recruit, show off),
- how participation was viewed (e.g. proactive, show support, provide funds/taxes, requires training, share computing resources)
- and words associated with public engagement (e.g. communicate, educate, outwards facing, share research data).

The thematic map was then refined using pen and paper, in conjunction with viewing the coded extracts on the computer, to narrow it down to six overarching themes. The themes were then examined as a cohesive body for consistency and to ensure that they addressed the research questions well. With these criteria satisfied, each theme was named. While the themes appear broad, this is in part because the interview questions covered a variety of aspects concerning public engagement.

Although attempts were made to include a diverse group of people to interview, it is important to note that the thematic analysis did not focus on the characteristics (age, gender, country of affiliation) of the scientists, as the interviews were not meant to address the second research question of this project (see Table 3.1). This decision was reinforced by the results of the quantitative analysis, which showed that outreach experience was the most important influencing factor: only one of the 19 interviewees had never participated in outreach and it was therefore impractical to draw comparisons in the qualitative analysis between those with and without outreach experience. The second key factor in the analysis of the survey data was age. However, the influence of age in the quantitative analysis was determined by treating it as a continuous variable and not as a categorical one of younger/older researchers. Further, the role of gender, which was only relevant to a small degree to begin with, can vary from country to country (see § 2.5). Therefore, given the diversity within the multicultural context of particle-physics research and the few overlapping intersectional characteristics among the interviewees, the analysis was performed without taking into account their characteristics. These are nevertheless mentioned in Chapter 5 to demonstrate that the interviews were not conducted with a homogeneous demographic.

3.7 Research ethics

Ethics approval for conducting this doctoral research was sought from both CERN and UWE.

Because of the nature of its research, CERN does not have a research ethics committee. The closest body in the Organization is the Office of Data Privacy, which was established under Operational Circular № 11 (CERN Human Resources Department, 2019) and which only came into force on 1 January 2019 – well after the end of the data-collection phases. Meetings were therefore held prior to the start of data collection with the CERN Legal Service and with the CMS collaboration's highest decision-makers – the Spokesperson and the Chairperson of the Collaboration Board (the latter representing all of the institutes that make up the CMS collaboration) – to seek their approval for conducting the research using the CMS database and mailing lists. With regards to accessing the CMS internal database, it was established that no personal information about individuals that was gathered from the database would be made public during the course of the research or indeed after it. Details of the research, including the original proposal and the documents relating to the data collection from human subjects, were provided to both parties, who gave the research their approval and support for the protocols.

The formal letter of support from CMS was included in the application for ethics approval made to the UWE Health and Applied Sciences Faculty Research Ethics Committee. The application made on 18 September 2014 was initially for the survey-based data collection and included the research protocol, a survey draft and the accompanying consent and debrief documents. It made clear that the research did not involve members of an at-risk group; that the participants would face no risks, either to their person or to their careers/research/funding as a result of responding to the survey or participating in the interviews; that there was no risk to the doctoral researcher from conducting the research; that participants could withdraw their consent within a pre-defined time window; and that the data would be stored securely during the research (see § 3.8). Conditional approval was granted on 3 November 2014. Along with the requested changes, an amendment was submitted on 27 January 2015, requesting permission to preserve data collected from the project instead of deleting all of it at the project's completion. The request for data preservation was supported by the CERN Legal

Service, who, having been consulted prior to making the request, were satisfied that all survey responses would be treated as confidential and the data would be anonymised before being made public at the end of the research. The ethics application received unconditional approval on 2 February 2015. A second amendment to the existing ethics approval was submitted on 14 October 2016 regarding the interview-based data collection, with the appropriate accompanying documents, and was approved on 20 October 2016.

3.7.1 Researcher positionality

There is something poetic about mentioning researcher subjectivity when studying those who explore the immutable laws of the universe and how they are described – objectively! – by elegant mathematics.

Reflexivity, according to Etherington (2004, pp.31–32), is "the capacity of the researcher to acknowledge how their own experiences and contexts (which might be fluid and changing) inform the process and outcomes of inquiry". It is important to contextualise my unique position as both an insider and an outsider, and the influence it has had on this research project and on my professional outlook. For most of the time that I was conducting this doctoral research, I worked as a science communicator at CERN, first for the CMS Communication Group and later for CERN's Education, Communication and Outreach group, embedded with the subjects of this study. My approach to science communication evolved as I immersed myself deeper into my research and all of the accompanying literature on public engagement. I sought to bring some of these ideas into practice at work and discussed them openly. Also, given more than a decade spent at CERN, I grew close to many of the scientists whose input I sought for this research, both through the survey and through the interviews. Several of those I did not know personally, I knew of, and I was a recognisable figure to a large part of CMS. Those I worked with most regularly were also aware of the aspects of public-engagement research that I had sought to incorporate into CERN's outreach activities. Despite all of this, the scientists took the personal interviews as an opportunity to be transparent and honest with me, even voicing criticisms where they felt it necessary. I never felt they were giving me the answers they thought I wanted to hear.

For my own part, I have no doubt that my unique observations and interactions outside of the context of this project have shaped my analysis of the interviews, not diminishing but strengthening the work. Throughout my research, I have not intentionally adopted a favourable stance towards my former colleagues and have made my best attempt to present the findings fairly and accurately.

3.8 Research data management

Research data management (RDM) has rightly received a great deal of scrutiny in recent years, not just regarding the secure storage and processing of personal data but also the timely and thorough deletion of personally identifiable information. However, there is a tension between deletion of academic research data and publicly archiving them for future scholars to reuse. Advocates of open and reproducible science have called for research data to be made available openly along with the outputs that they lead to, as described in the community-authored guide to reproducible data science known as *The Turing Way*[*] (The Turing Way Community, 2021). Although a formal RDM plan was not required at the start of this research, the ethics application nevertheless included details about both the immediate secure storage of the data and the long-term archival plans, as described below.

3.8.1 Data storage

Two kinds of data were collected over the course of the project: tabular data from (a) the survey responses and (b) the CMS internal database (see § 3.3.2.2), and transcripts from the interview recordings. As the researcher was based at CERN at the time, it was decided to store all datasets on CERN's on-site servers, in a directory only accessible freely to the researcher himself. When the data were downloaded to the researcher's computer for analysis, they were stored in an encrypted container. Further, the computer's hard disk is itself encrypted and remained locked whenever left unsupervised. The exception was a copy of the interview recordings, which were shared via UWE servers with a university-affiliated transcriptionist for transcribing following standard UWE procedures at the time. Following the end of the researcher's affiliation with CERN in 2021, all the data were deleted from CERN servers and transferred to UWE servers for the duration of the doctoral project.

3.8.2 Data archival

Both kinds of data will be uploaded to the Zenodo repository[†] at CERN, following specific protocols for each. CERN's Office of Data Privacy and the UWE Data Protection Office will be consulted before any data are deposited on Zenodo.

The tabular data from the survey alone, which does not contain any identifiable or personal information from the respondents beyond their responses to the survey questions, will be shared as

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[*] https://the-turing-way.netlify.app/

[†] https://zenodo.org/

open access on Zenodo. Aggregate data from the CMS database will also be provided for completeness, whilst adhering to the data-protection requirements. In order to explore the relationship between the attitudes and variables such as the respondent's age and gender, this information will also have to be provided. However, the datasets combining the survey data and the respondents' data (age, gender, scientist type/role only) will be stored on Zenodo under "restricted access", with only the researcher able to selectively provided access to those who request it. This is necessary in order to maintain the confidentiality of the respondents, although the datasets themselves do not contain any information that could cause harm to individuals. Synthetic versions of the personal data may subsequently be made available openly if they satisfy the data-protection requirements.

The transcripts, even with redactions of personal information, carry a greater risk of identification and will therefore only be stored under "restricted access" on Zenodo.

3.9 A word on open science and reproducibility

In the spirit of open and reproducibly science, I made every attempt to rely on free and open-source software (FOSS) for the collection and analysis of the data presented in this thesis so that my work can be independently verified by anyone who desires without having to face the barrier of expensive and proprietary software. As mentioned above, the quantitative data analysis was done using the R programming language (R Core Team, 2022) while the qualitative analysis used QualCoder (Curtain, 2021), both running on a Linux computer. The FOSS bibliography software Zotero[*] was used to store the literature and generate the references list. This document itself is written in R Markdown (Allaire *et al.*, 2022), using the `bookdown` package (Xie, 2021a) and the final PDF generated is meant to be reproducible: by taking the plain-text source files – and by acquiring the data themselves – one can rebuild the entire document, including all the data visualisations and tables.

Other research outputs, with the exception of the final of three conference presentations, are archived on Zenodo: see Rao (2016a), Rao (2016b), Rao (2016c), Rao (2016d) and Rao (2017). The source files for the three conference presentations and one poster can also be found on my GitHub profile.[†]

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[*] https://www.zotero.org/

[†] https://github.com/RaoOfPhysics/

Chapter 4

Survey analysis

A quantitative analysis of the survey data is presented in this chapter. I first present the demographics of the survey respondents (§ 4.1) and the responses to the individual survey questions (§ 4.2) followed by a statistical treatment of the data, in the form of an exploratory factor analysis (§ 4.3). This chapter primarily addresses the first two research questions of this thesis (**RQ1** and **RQ2**), but partially touches upon the third (**RQ3**) as well:

- **RQ1**: “What are the attitudes towards outreach within the particle-physics community, including the motivations for – and barriers against – participating in outreach activities?”
- **RQ2**: “Do these attitudes towards outreach within the particle-physics community vary with respect to age, gender and outreach experience?”
- **RQ3**: “How, if at all, are these attitudes influenced by (a) differing expectations from funding bodies and (b) being part of large, international collaborations?”

4.1 Demographics of survey respondents

Over the data-collection period, 391 valid responses were received, representing 8.23% of CMS scientists (i.e. excluding collaboration members classified as administrative, technicians and others). Although the proportion is lower than was anticipated, the total number of responses is still suitably large enough for the analysis described here.

4.1.1 Gender

The gender breakdown of the respondents[*] is listed in Table 4.1, together with that for the total number of scientists in the CMS collaboration.[†] Therefore, 7.82% of all male CMS scientists and 10.17% of all female CMS scientists responded to the survey. The differences in the response rates are significant, as determined by the Chi-squared test without the Yates's correction (p-value: 0.0258; 95% CI: -0.0457, -0.0012).

Table 4.1: The gender representation in the survey responses and among all CMS scientists

	Survey		CMS total	
Gender	N	%	N	%
Men	307	79%	3924	83%
Women	84	21%	826	17%

Note:
CMS total as of 2 July 2015

4.1.2 Age distribution

Figure 4.1 shows (a) the distribution of respondents' ages, in groups of five years, 20-year-olds being grouped with those in the 21–25 range, and (b) the relative density of the gender-wise age distributions. There is no obvious pattern to report. The respondents can be grouped into two: **young** or early-career scientists (up to 40 years old) and **senior** scientists (aged 41 and above).[‡] Table 4.2 shows a nearly even split in the survey responses between the two categories, although senior scientists responded to the survey in greater proportion. N.B.: The age of the respondent listed as 100+ was recorded incorrectly in the CMS database; this respondent was filtered out of final statistical analysis.

Table 4.2: The representation of both age groups in the survey responses and among all CMS scientists

	Survey		CMS total	
Age group	N	%	N	%
Young	194	49.6%	2885	60.7%
Senior	197	50.4%	1865	39.3%

Note:
CMS total as of 2 July 2015

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[*] At the time of collecting these data, CMS only allowed its members the choice of one of two genders, based on their passports or national ID cards. I am not aware if this policy has changed since them.

[†] One of the scientists had an empty gender field in the database.

[‡] This cut-off was chosen considering the following factors: For one, the mean age of the survey respondents was 42.5, while the median age was 41. Secondly, for the purposes of awarding their achievements, the CMS collaboration considers as "young" anyone who has pursued less than ten years of research following their PhD; since the average age of completion of PhDs in natural sciences varies from ~25 to ~35 around the world, it makes sense to choose ~30 as the age of PhD completion and add ten years to it.

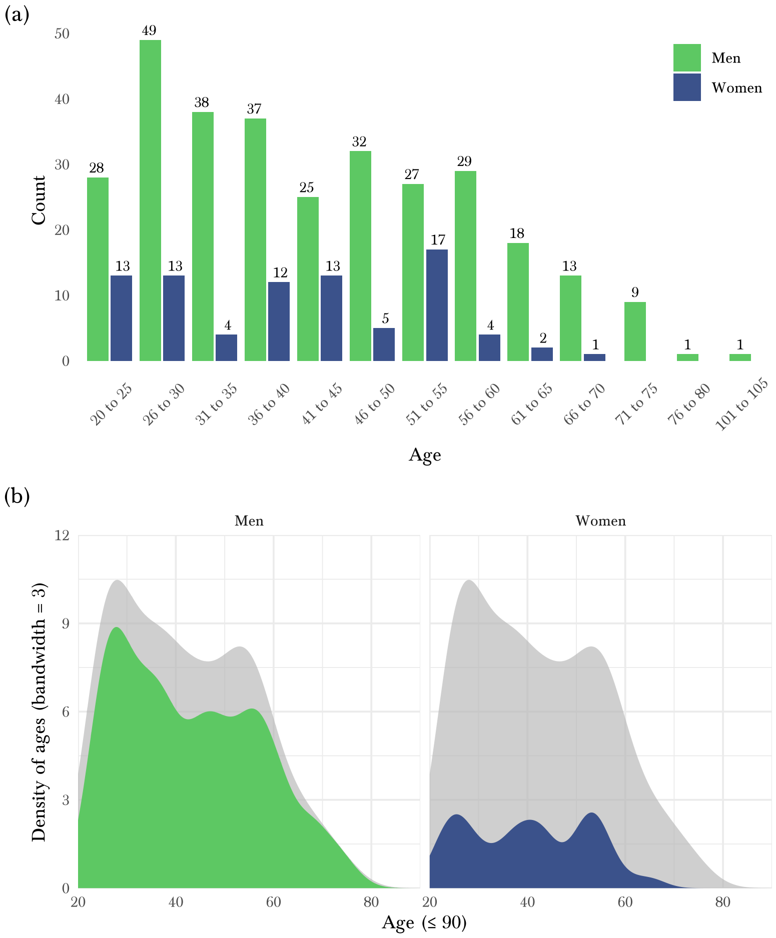

Figure 4.1: Distribution of the ages of the survey respondents

4.1.3 Scientist type/role

The type/role of each scientist who responded to the survey was retrieved from the CMS database, and is shown in Table 4.3. Although we have previously included graduate students as physicists, for the purposes of delineating the demographics, they are considered separately here. A total of 100 respondents are students (doctoral or non-doctoral). The turnout of engineers (here showing electronics engineers, mechanical engineers and software engineers grouped with those listed simply as “engineers”) was too low for a meaningful statistical analysis of the various groups. Looking up the person in the survey who is listed as “Administrative” in the CMS internal database shows that they should have been registered as “Physicist”, and their responses are therefore considered valid for the purposes of the analysis.

Table 4.3: The roles of the respondents, according to the CMS database

	Survey		CMS total	
Scientist type/role	N	%	N	%
Physicist	254	65%	1930	41%
Doctoral Student	79	20%	956	20%
Engineer	36	9%	959	20%
Non-Doctoral Student	21	5%	905	19%
Administrative	1	0%		

Note:
CMS total as of 2 July 2015

4.1.4 Outreach experience

Outreach experience was one of the dependent variables against which the analysis was performed, and its values were self-reported. The survey posed the question *"Have you ever participated in an outreach activity?"* The variable was dichotomous: respondents could choose *Yes* or *No* to the mandatory question. Most of the respondents (n=348, 89%) reported participating in outreach at some point in the past, and most of these (n=329, 84% of total) claimed to have participated at least once in the previous year. Table 4.4 shows the reported rates of outreach experience for men and women, with no difference in the gender-wise participation rates.

Table 4.4: Gender-wise breakdown of outreach experience

	Experience?		
Gender	Yes	No	In last year
Men	274 (89%)	33 (11%)	259 (84%)
Women	74 (88%)	10 (12%)	70 (83%)

The survey also sought to gather data on time spent on outreach, although these data were not used for statistical analyses. The relationship between the number of outreach events and time spent on them can be asymmetric: some activities like guided tours and responding to journalists can be done repeatedly and with minimal preparation, while others like interventions in school curricula require significant preparation for – and follow-up from – a single event. To decouple the two, and to examine their relationship with one another, the respondents were asked to report values for both time and number of events on five-point scales (with a sixth option of "0"/"None" for those with no outreach experience in the previous year). As can be seen in Figure 4.2, the number of events participated in and the amount of time spent doing outreach are both low (clustering near bottom left): 224 (68%) participated in a maximum of five activities in the year, while cumulatively 220 (67%) reported spending either up to 10 hours in total on outreach (n=117) or up to 2 hours a month on average (n=103).

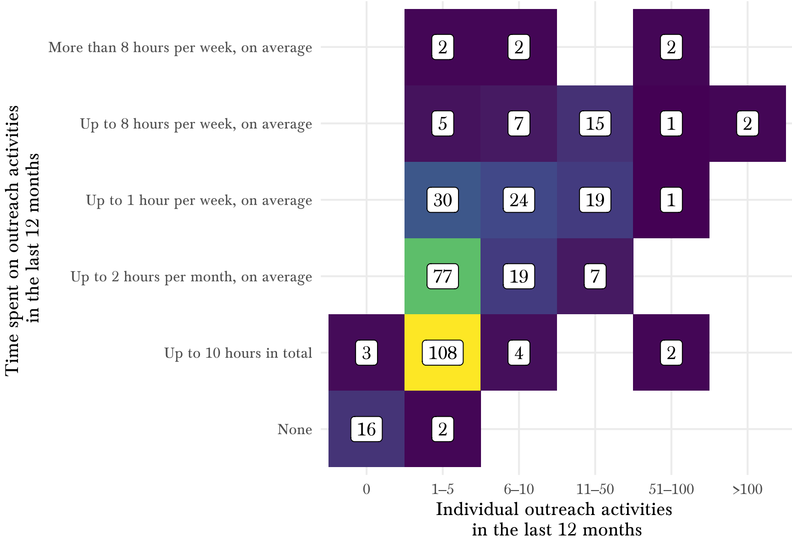

Figure 4.2: Number of outreach activities versus time spent on them

Table 4.5: Behavioural intention to participate in outreach in the future

	Experience?		
Behavioural intention	Yes	No	Total
Positive	243	6	249
Neutral	96	21	117
Negative	9	16	25

Referring to the theory of planned behaviour by Ajzen (1991), Poliakoff and Webb (2007, p.245) note that “the best predictor of whether a scientist will take part in a public engagement activity is the direction (shall I/shan’t I) and strength (how much do I want to/not want to) of their [behavioural] intention”.[*] This intention to participate in outreach in the future was evaluated by asking the respondents to select one of three statements: “I plan to participate in an outreach activity in the next 12 months,” “I may participate in an outreach activity in the next 12 months,” and “I do not plan to participate in an outreach activity in the next 12 months.” These statements signify positive, neutral and negative behavioural intention, respectively. Most responses were *positive* (n=249), followed by *neutral* (n=117), with a small fraction (n=25) showing negative behavioural intention. The differential behavioural intentions – among those with and without outreach experience – are shown in Table 4.5. Overall, it was overwhelmingly positive amongst those having participated in outreach (~70%), whereas those without prior outreach experience show neutral or negative behavioural intentions.

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[*] These responses were not part of the statistical analysis presented later in this chapter. A comparison with Poliakoff and Webb (2007) was not attempted in this research.

4.1.5 Outreach requirements of funders

Funding agencies around the world are increasingly requiring scientists to participate in communication that reaches beyond their peers (Palmer and Schibeci, 2014) and researchers are being asked to include their outreach plans when applying for grants. Nevertheless, these expectations may not be communicated explicitly, leading to some scientists not being aware of the outreach requirements placed on them. The survey asked the respondents to note whether their funding agency (or their institution, acting as a proxy for the funding agency) required them to participate in outreach. These responses were used as dependent variables to assess the role of funding agencies' requirements on attitudes towards outreach. The respondents were also asked to rate on a five-point Likert-type scale whether they felt these aforementioned requirements were inadequate (1), excessive (5) or just right (3), but they could also choose `NA` (not applicable) if they had no opinion on this matter.

Table 4.6: Requirements to participate in outreach

Do funders require outreach?	N	%
Yes	86	22%
No	168	43%
Don't know	137	35%

Adequacy of requirements	N	%
1: Very excessive	1	0%
2	15	6%
3: Just right	125	52%
4	71	30%
5: Very inadequate	27	11%

As the left half of Table 4.6 shows, most of the survey respondents either did not know these requirements ("Don't know") or stated that they were not required to participate in outreach ("No"), with fewer than a quarter stating that they were required by their funders to participate in outreach ("Yes"). Although the numbers cannot be compared statistically due to the size differences in both samples, only 4 out of 43 (9.3%) who had never participated in outreach reported being required to participate in outreach, compared with 82 out of 348 (23.6%) who had outreach experience. The right half of Table 4.6 shows that – among those who responded to the second question* – over half felt their requirements were just right. However, it is important to note that 39% of the survey participants did not express an opinion about their outreach requirements and chose the `NA` option.

Figure 4.3 includes the `NA` responses in the right-most column. It shows that nearly all of those who did not leave a response to the second question responded either "No" or "Don't know" to the first. The figure also shows that among those who provided their opinion (i.e. ignoring the right-most column with `NA`s) just over half of those who did not know their requirements (20 out of 39 in the bottom row)

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*All of the `NA` responses were removed for making this table; the table therefore shows the relative proportions of those who responded to the survey question.

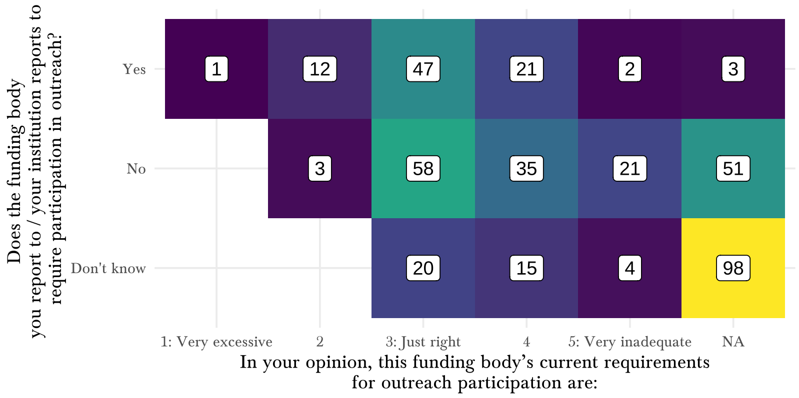

Figure 4.3: Comparing outreach requirements with their perceived adequacy

felt that this status quo was just right; the remaining felt that their requirements were inadequate or very inadequate, suggesting that they had not been made aware of it but felt they *should* have been. Similarly, 56 of those who were *not* required to participate in outreach (middle row) felt their requirements were inadequate or very inadequate.

These data suggest that the scientists participate in outreach even without being required to do so and that a majority supported the status quo with regards to their requirements, whether they were required to participate in outreach or not.

4.2 Attitudes towards outreach

This section addresses the principal research question (**RQ1**) of this thesis. As a reminder, according to Bohner and Dickel (2011, p.392), "An attitude is an evaluation of an object of thought." In this research project, attitudes are evaluated across three dimensions: the perceived benefits of outreach participation (§ 4.2.1), the scientists' wider perceptions about outreach (§ 4.2.2) and groups targeted by the scientists for communication about their research (§ 4.2.3).

4.2.1 Benefits of outreach participation

Understanding *why* scientists participate in outreach is key. This can be studied based on the benefits that are derived from outreach participation, according to the scientists themselves. Benefits were considered as consisting of personal benefits (§ 4.2.1.1) and benefits to wider society (§ 4.2.1.2). These were each assessed using nine five-point *Agree–Disagree* Likert-type statements.

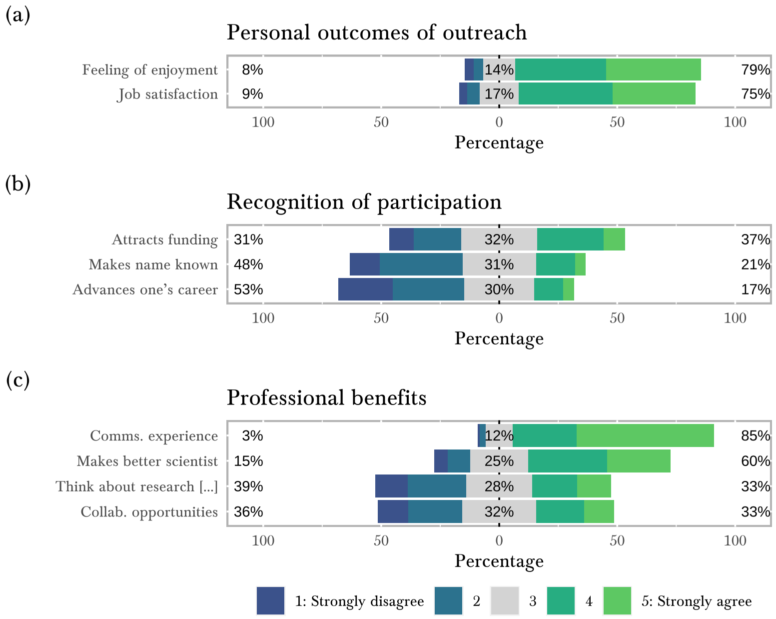

Figure 4.4: Personal benefits of outreach participation

4.2.1.1 Benefits to oneself

Personal benefits were divided into three categories, as seen in Figure 4.4: (a) personal outcomes of outreach, (b) recognition of participation and (c) professional benefits.

Outreach participation can be personally rewarding to the scientists involved. Their views on such personal outcomes were evaluated by asking the respondents if outreach participation gave them a feeling of enjoyment (*agree* or *strongly agree*: n=305/388, 79%) and job satisfaction (*agree* or *strongly agree*: n=290/388, 75%). Spearman's correlation coefficient of 0.74 shows that the ratings for the two personal outcomes are strongly correlated.

One of the constructs Poliakoff and Webb (2007) consider in their work is "recognition of participation", which they measure with statements on whether participation attracts research funding and whether it helps advance one's career. I added a third statement, on whether participation makes the scientist's name known. The responses to all three statements are shown in Figure 4.4 (b), which suggests that the particle-physics community is not strongly motivated by any recognition that outreach participation brings. Indeed, only a little over a third felt outreach participation attracts funding (*agree* or *strongly agree*: n=145/389, 37%), while nearly half disagreed that it makes their name known (*disagree* or *strongly disagree*: n=186/389, 48%) and over half disagreed that it advances their career (*disagree* or *strongly disagree*: n=207/388, 53%). Responses to the two statements about making their name known and career advancement are moderately correlated (Spearman's correlation coefficient: 0.43).

The notion that scientists might be motivated professionally by the communication experience that outreach participation imparts received considerable support, with more than half strongly agreeing with the statement (*strongly agree*: n=226/389, 58%; *agree*: n=105/389, 27%). (In § 5.2.4.2, I discuss how this communication experience translates into better communication among peers.) A majority also felt that outreach participation made them better scientists (*agree* or *strongly agree*: n=232/386, 60%). Responses to the two statements are only weakly correlated (Spearman's correlation coefficient: 0.38).

Two other professional outcomes of outreach, according to some proponents of the public-engagement paradigm of science communication, are that scientists begin to think about their research in novel ways and that outreach results in new collaboration opportunities. These two "engagement"-like statements saw the votes split but leaning slightly towards disagreement, suggesting that such views are not widely held in CMS: around a third agreeing with the first notion (*agree* or *strongly agree*: n=129/386, 33%) and a similar number with the second (*agree* or *strongly agree*: n=126/384, 33%). Responses to the two statements are moderately correlated (Spearman's correlation coefficient: 0.55).

The data show that personal outcomes and communication experience are the most identified benefits to the scientists themselves, while they do not believe that outreach participation is beneficial to their careers directly.

4.2.1.2 Benefits to society

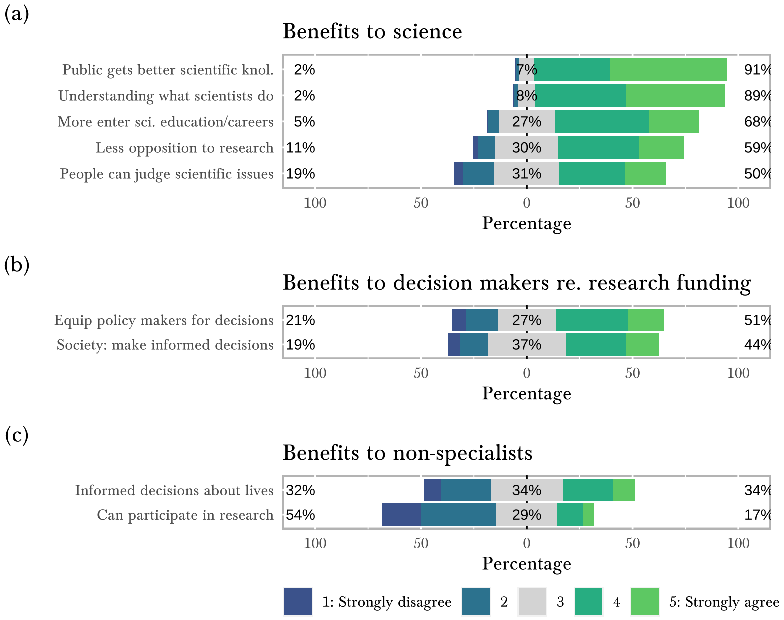

Figure 4.5: Benefits of outreach participation to society

Figure 4.5 shows the responses to the nine statements on benefits to wider society, split into three areas: (a) benefits to science itself, (b) benefits to decision makers regarding funding of science and (c) benefits to non-specialists. The findings suggest that views associated with the knowledge-deficit model are key motivators for outreach participation within the particle-physics community, with the benefits of outreach to science itself rated most highly. Wide support was received for statements suggesting that outreach results in the public gaining a better understanding of science (*agree* or *strongly agree*: n=353/389, 91%) and improving their understanding of what scientists do (*agree* or *strongly agree*: n=348/389, 89%). Half of the respondents felt that outreach enables non-specialists to judge scientific issues for themselves (*agree* or *strongly agree*: n=195/389, 50%), and reduces their opposition to research (*agree* or *strongly agree*: n=231/389, 59%). A further benefit was that the pursuit of science courses and science careers would rise (*agree* or *strongly agree*: n=263/387, 68%).

The impact that outreach has on those with the purse strings was also an important driver, with over half agreeing that outreach results in policy makers being better equipped to make decisions about research funding (*agree* or *strongly agree*: n=198/387, 51%), and with a little less than half agreeing that society can make informed decisions about research funding (*agree* or *strongly agree*: n=171/386, 44%).

However, only around a third felt that particle-physics outreach would result in people being able to make informed decisions about their own lives (*agree* or *strongly agree*: n=133/388, 34%) and over half disagreed with the idea that non-specialists could in any way participate in scientific research (*agree* or *strongly agree*: n=67/389, 17%). These data suggest that respondents view the greatest benefits to society from scientists participating in outreach as ones that improve the standing of science in society but not ones that empower members of wider society. How these views may relate to the specialised nature of particle-physics research and the lack of relevance to day-to-day human life is presented in the conclusions chapter (§ 7.1).

4.2.2 Perceptions about outreach

A total of 29 *Agree–Disagree* Likert-type statements regarding general perceptions about outreach were also presented in the survey. These covered nine categories: moral norms (§ 4.2.2.1), perceived behavioural control (§ 4.2.2.2), perceptions of non-specialist publics (§ 4.2.2.3), environmental constraints (§ 4.2.2.4), language of outreach (§ 4.2.2.5), subjective norms (§ 4.2.2.6), perceived suitability of research (§ 4.2.2.7), outreach plans and research funding (§ 4.2.2.8), and the role of culture and policy (§ 4.2.2.9).

4.2.2.1 Moral norms

The *Bodmer report* (Royal Society, 1985) called upon scientists to consider it their duty to communicate with the public. Some 30 years later, this moral norm is firmly embedded in the particle-physics community. As shown in Figure 4.6, most respondents strongly agreed (n=203, 52%) or agreed (n=111, 28%) with the statement "I have a duty as a scientist to take part in outreach activities." Similarly, the statement "It is important for scientists to take part in outreach activities because taxes from citizens fund research," received considerable agreement (*strongly agree*: n=146, 37%; *agree*: n=143, 37%). However, despite similar numbers, these two moral norms are only weakly correlated, as indicated by Spearman's correlation coefficient of 0.34, suggesting that the sense of duty may not arise from obligations to tax payers.

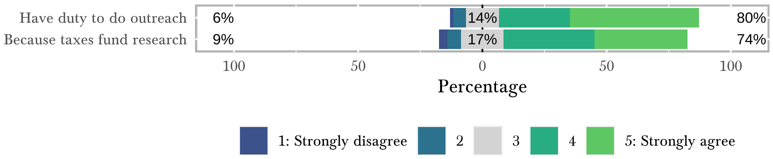

Figure 4.6: Moral norms for outreach participation

4.2.2.2 Perceived behavioural control

Previous research shows that "a scientist's perception of his or her own ability to participate in a public engagement activity has a significant effect on his or her intention to participate" (Poliakoff and Webb, 2007, p.256). As shown in Figure 4.7, five statements were chosen to evaluate this facet. "I feel confident that I could answer questions asked by the public," was the most positively received (*strongly agree*: n=146/387, 38%; *agree*: n=168/387, 43%), followed by "I feel confident that I could prepare the necessary materials to participate in an outreach activity," (*strongly agree*: n=174/387, 45%; *agree*: n=128/387, 33%) and "It is easy for interested scientists to get involved in outreach," (*strongly agree*: n=88/389, 23%; *agree*: n=139/389, 36%).

The majority of respondents disagreed with the fifth statement: "Scientists do not have the communication skills for discussing their work with the non-specialist public." At the same time, over half agreed with the related statement, that "Scientists should get help from professional communicators when communicating their findings to the non-specialist public," (*agree* or *strongly agree*: n=205/387, 53%; *neutral*: n=123/387, 32%; *disagree* or *strongly disagree*: n=59/387, 15%). Despite the differences in responses, both statements are weakly correlated, with Spearman's correlation coefficient of 0.31.

The scientists showed confidence in their own abilities with regards to outreach participation, including possessing the necessary communication skills, but were also open to the idea of getting help from communication professionals.

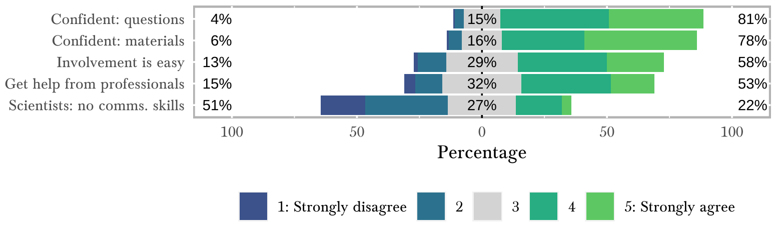

Figure 4.7: Perceived behavioural control for outreach participation

4.2.2.3 Perceptions of non-specialist publics

Without – for the moment – taking a stance on the rhetorical (f)utility of the so-called "deficit model" of science communication, it is evident from the survey data that beliefs attributed to this model are prevalent within the particle-physics community. As seen in Figure 4.8, *Agree–Disagree* Likert-type statements in the survey showed support for the following statements: "In general, people have little understanding of what scientists do," (*agree* or *strongly agree*: n=277/386, 72%), "The public lack knowledge/education about the facts of science," (*agree* or *strongly agree*: n=261/385, 68%) and "The general public does not appreciate how science affects them" (*agree* or *strongly agree*: n=182/388, 47%). However, the statement "There is a lack of interest in science among the general public," received less agreement (*agree* or *strongly agree*: n=108/389, 28%); this is not dissimilar to the findings of the Royal Society survey, which also showed little support for the idea that the public lacks an interest in science (Royal Society, Research Councils UK and Wellcome Trust, 2006). Wider society therefore is seen as being interested in science but not being familiar with its practice and consequences.

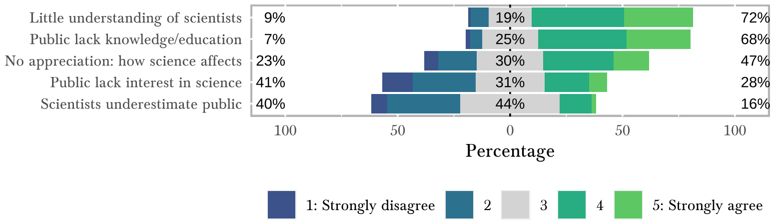

Figure 4.8: Perceptions of non-specialists with regards to science

These notions also appear to be deep-rooted. Only a small number felt that “Scientists underestimate how knowledgeable the general public is about science,” (*agree* or *strongly agree*: n=62/386, 16%). So, the particle-physics community is quite confident in its unflattering views of the non-specialist’s perceptions of science.

4.2.2.4 Environmental constraints

Barriers preventing outreach participation can be external – or environmental – in nature. For example, previous research has shown that some scientists cited the need to spend more time on research as a barrier to greater participation in outreach (Royal Society, Research Councils UK and Wellcome Trust, 2006, p.38). The survey addressed three such aspects, as shown in Figure 4.9. None appeared to be a strong barrier, with nearly half disagreeing with the statement “I would participate in outreach activities if there was money to support participation,” (*disagree* or *strongly disagree*: n=180/385, 47%), half disagreed with “Participating in outreach takes too much time away from research,” (*disagree* or *strongly disagree*: n=193/388, 50%) and less than a tenth showed agreement with “Commercial barriers prevent greater participation in outreach,” (*agree* or *strongly agree*: n=31/381, 8%).

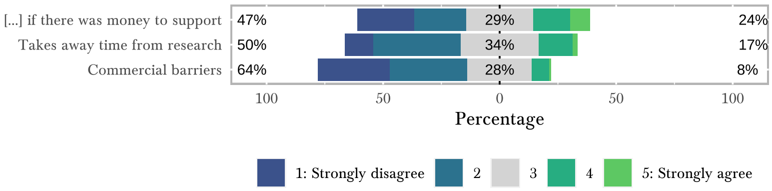

Figure 4.9: Environmental constraints to outreach participation

The strong disagreement on commercial barriers may have to do with the fact that particle physics does not inherently have commercial outcomes; that is, it is not so much ruled out as a barrier as it is harder for the respondents to evaluate as one. This is also reflected in the low ranking of industry as an audience for these researchers (see § 4.2.3, and is further discussed § 6.4).

4.2.2.5 Language of outreach

As an international laboratory with over 100 nationalities represented, CERN is a multicultural and multilingual organisation. Before accounting for language preferences for outreach participation, I consider two points:

1. Although the CMS collaboration has representatives from tens of countries, only a small fraction

of the collaboration is based at CERN; as most members of CMS are not based at CERN, they may have the opportunity to participate in outreach activities in their home institutes. Therefore, the scientists may end up involved in outreach activities conducted in one of their native languages.

2. Outreach activities conducted by CERN are mainly in English or French (the official languages of the organisation), although targeted programmes held on-site are conducted in the preferred language of the participants. For example, when a group of students from Germany visits the laboratory for a tour, they are guided in German; German-speaking scientists not confident in their English or French abilities thus have the option to join German-language events.

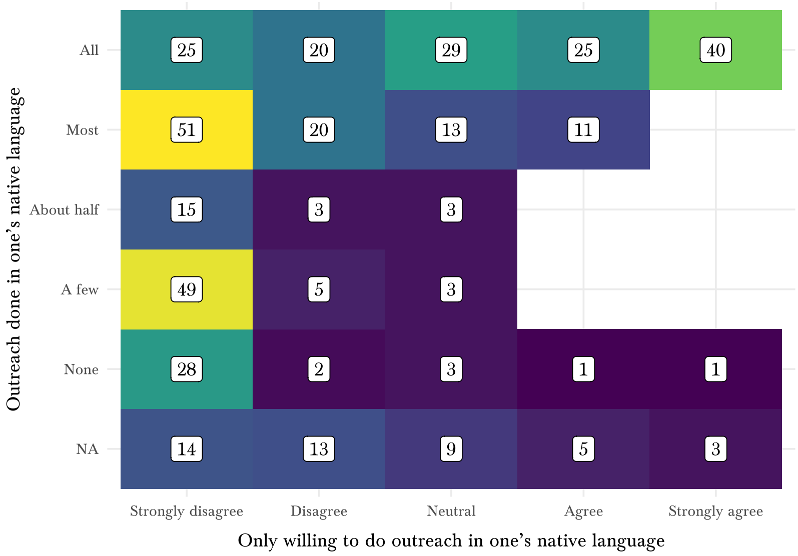

Figure 4.10: Importance of language of activity vs actual language-representation of activities

The survey asked the respondents both how likely it was that they would only participate in outreach activities in their native languages and how many of the activities they had previously participated in were conducted in their native language. Most disagreed that language played a decisive role in determining their outreach participation (*strongly disagree*: n=182, 47%; *disagree*: n=63, 16%). However, looking at the left-most column in Figure 4.10, 76 of those who strongly disagreed with the idea that their participation was contingent on the activity being in their native language did end up largely joining events in their native tongue ("Most" or "All"). Indeed, as indicated by a Spearman's correlation coefficient of -0.04, there is a very weak correlation between the two measures, suggesting that – despite a lack of preference – the diversity of language options available for those at CERN to participate in outreach, or the prevalence of outreach events in their preferred languages at their home institutes, means that there are adequate opportunities to do so in one's language of choice. On the other hand, among the 139 who only participated in outreach events in their native language, 65 expressed a willingness to only participate in events held in their native tongues. Note that those without outreach experience, and who left no response to the second question (shown by the `NA`s in the bottom row), also generally disagreed with the idea that their outreach participation was native-language-dependent.

4.2.2.6 Subjective norms (or the "Sagan effect")

No discussion about the attitudes of scientists towards outreach participation can be complete without addressing the so-called "Sagan effect", which I have discussed in § 2.5. Named after astronomer Carl Sagan, this phenomenon is described as:

> "… the perception that popular, visible scientists are worse academics than those scientists who do not engage in public discourse." (Martinez-Conde, 2016, p.2077)

It suggests that academics might not approve of their colleagues' outreach participation, which might in turn dissuade some from outreach. Four *Agree–Disagree* Likert-type statements addressed the Sagan effect, two considering a researcher's peers and academic setting, and two evaluating the fear of risk to oneself. As seen in Figure 4.11, these views are not expressed within CMS. Respondents expressed agreement with the statements "My colleagues would approve of my taking part in an outreach activity," (*agree* or *strongly agree*: n=250/389, 64%) and "My home institute generally supports scientists who take part in outreach activities," (*agree* or *strongly agree*: n=264/389, 68%). The two statements were moderately correlated with Spearman's correlation coefficient of 0.56.

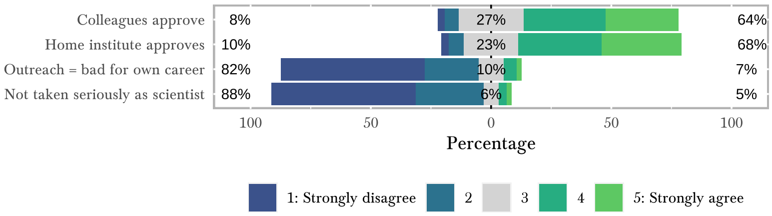

Figure 4.11: Subjective norms regarding outreach

On the other hand, the statements associated with fear – namely "Taking part in an outreach activity could be bad for my career," (*disagree* or *strongly disagree*: n=320/389, 82%) and "I would not be taken seriously as a scientist by the public if I participate in outreach," (*disagree* or *strongly disagree*: n=341/387, 88%) – received overwhelming disagreement, although they were only weakly correlated with each other (Spearman's correlation coefficient: 0.3).

We can conclude that the Sagan effect does not act as a barrier to outreach participation for the particle-physics community. Overall, outreach participation is viewed favourably in this academic milieu.

4.2.2.7 Perceived suitability of research

In their work, Poliakoff and Webb (2007) evaluated the extent to which scientists perceived their research as being suitable for outreach. Here, I use three statements to evaluate whether such intrinsic considerations acted as barriers to outreach participation. The respondents generally disagreed with all three – "My research is too complex for an outreach activity," (*disagree* or *strongly disagree*: n=290/389, 75%), "To communicate with the public, I have to overly simplify my work, which reduces its scientific correctness," (*disagree* or *strongly disagree*: n=197/388, 51%) and "I might feel forced to defend my research when participating in outreach," (*disagree* or *strongly disagree*: n=179/389, 46%) – as shown in Figure 4.12.

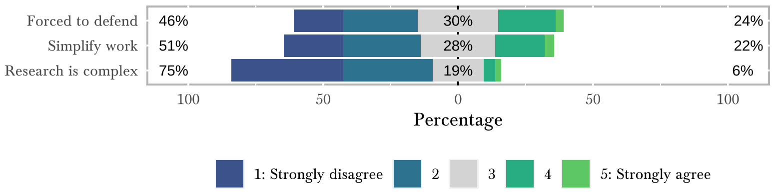

Figure 4.12: Perceived suitability of particle physics for outreach

From the strong disagreement shown to the first statement, we can conclude that the particle-physics community does not consider their research area to be inherently unsuitable for outreach activities and we can rule this out as a barrier to outreach participation. I speculate that the slightly greater agreement with the third statement is because of the costs associated with particle-physics research infrastructure and fear-mongering related to the switching on of the Large Hadron Collider.

4.2.2.8 Outreach plans and research funding

I have mentioned that funders are introducing mandatory outreach requirements when researchers apply for grants (e.g. Palmer and Schibeci, 2014). In this regard, the expectations that scientists place on the funding bodies differ from what they believe they should themselves do, as seen in Figure 4.13: The vast majority agreed that funding bodies "should provide support for scientists to communicate their research to the non-specialist public" (*agree* or *strongly agree*: n=300, 77%; *neutral*: n=67, 17%; *disagree* or *strongly disagree*: n=24, 6%), but fewer than half agreed that "scientists should be required to provide details on how their research will be communicated to the wider society" in their applications for grants (*agree* or *strongly agree*: n=169, 43%; *neutral*: n=101, 26%; *disagree* or *strongly disagree*: n=121, 31%).

A related aspect concerns the role played by the local community in the decision-making process for building new research facilities, and less than half (*agree* or *strongly agree*: n=166/385, 43%) would involve the local community in such a process.

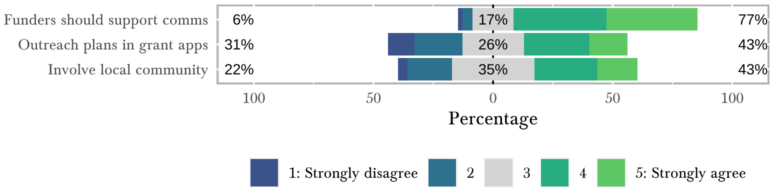

Figure 4.13: Outreach plans and research funding

The scientists echo previous research that asks for funders to provide structural support for outreach without requiring grant funding to be contingent on outreach participation. Whether awareness of the funding agency's requirements is a factor in influencing outreach participation is explored later in this chapter (§ 4.3), and the matter of the inclusion of outreach plans in funding applications is further explored in § 5.2.3.3.

4.2.2.9 The role of culture and policy

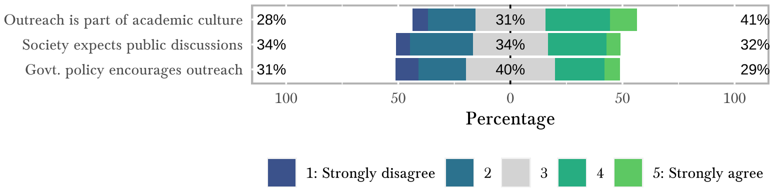

Figure 4.14: The influencing role of culture and policy

To understand whether perceptions of social norms in one's country can influence outreach participation, two related statements concerning nation-level cultural expectations pertaining to outreach were presented to the respondents: "In the country of my institute/university, outreach and public communication are part of the academic culture," (*agree* or *strongly agree*: n=159, 41%) and "In the country of my institute/university, society expects scientists to discuss their work in public (e.g. through media interviews, public lectures etc.)," (*agree* or *strongly agree*: n=126, 32%). Spearman's correlation coefficient for the statements is 0.67, indicating moderate correlation. Further, fewer than a third believed that "government policy encourages outreach" (*agree* or *strongly agree*: n=111/384, 29%; *neutral*:

n=153/384, 40%; *disagree* or *strongly disagree*: n=120/384, 31%).

Figure 4.14 shows the responses to three statements on the role of culture and policy in encouraging outreach participation. The responses are fairly evenly distributed across agreement, neutrality and disagreement, with very few strong views in either direction. Unfortunately there were insufficient responses from a large number of countries to investigate whether there were differences in attitudes by country or groups of countries (grouping them by socio-cultural parameters).

4.2.3 Groups targeted for communication

Table 4.7: Target groups for communication

Group short name	Full name used in survey
Research	
Colleagues	Your colleagues and collaborators / other people in your research field
Other scientists	Other scientists or experts outside your research field
Press officers	Press officers at your university/institute
Education	
Teachers	Teachers
University students	University students
School students	School students / pupils
Media	
General journalists	General journalists
Science journalists	Science journalists
Other media	Other media (writers, documentary makers)
Other	
Government	Government / politicians / policy makers
Industry	Industry / corporate sector / private companies
Non-specialist public	Non-specialist public

Table 4.8: The groups' characteristics chosen for the survey

	Range for Likert items	
Characteristic	1	5
Importance		
"How important is it for you personally to communicate your research with the following groups?"	Not important at all	Very important
Ease of communication		
"How easy is it for you to talk about your research with these groups?" (Not applicable = 0)	Very difficult	Very easy
Knowledge of particle physics		
"How knowledgeable do you think each group, as a whole, is about your research area?"	Not knowledgeable at all	Very knowledgeable

Scientists may favour or prioritise specific groups with whom to communicate their research. Analysis of the groups favoured by a community of scientists provides insight into the communication paradigms that prevail. Based on previous research – in particular the Royal Society, Research Councils UK and Wellcome Trust (2006) survey – and on feedback from the pilot-survey participants, twelve groups were chosen, as shown in Table 4.7.

The "favourability" of these groups for the particle-physics community is measured using three criteria: (i) the **importance** of the group for discussing one's research, (ii) the **ease** of discussing one's research with the group and (iii) the **knowledge** the group as a whole is assumed to have about particle physics. The range for the Likert-type items chosen to evaluate these characteristic criteria are shown in Table 4.8. Researchers who had never interacted with a particular group were presented with the option of selecting "Not applicable" for ease of communication (coded as "0" in the analysis). Therefore, the favourability rating could range from a minimum of 2 (1+0+1) to a maximum of 15 (5+5+5).

The cumulative scores for the favourability are shown in Figure 4.15; the jittered dots around each number on the X-axis show the distribution of ratings for each group while the box plots show the median rating, percentiles and any outliers. The ratings received from the respondents for the three individual criteria are shown in Figure 4.16.*

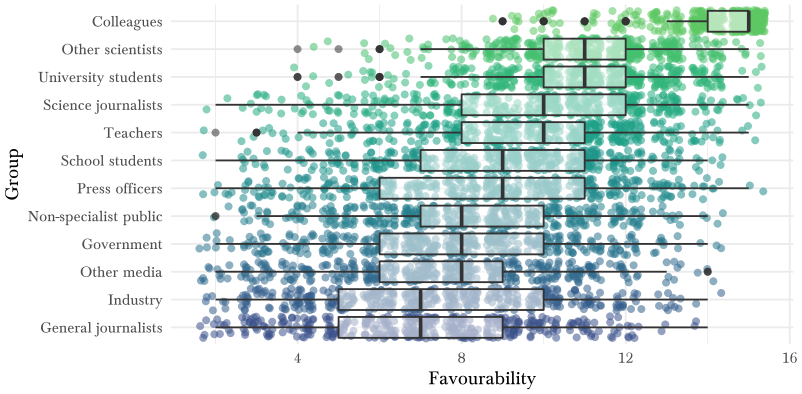

Figure 4.15: The favourability of each chosen group, based on the individual characteristic criteria

Perhaps unsurprisingly, the respondents rated their colleagues as the most favourable group. Colleagues topped the charts for all three criteria (with a mean of 14.04 and a median of 15).

The rest of the groups appear in clusters. Just below colleagues are other scientists and university students (similar medians but the former group has a slightly higher mean); university students ranked higher for both importance and ease of communication, but other scientists were rated as more knowledgeable. Groups within the academic sphere are thus considered as favourable for communication.

The groups that follow are science journalists and teachers, who serve as vectors for the

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[*] A table for the mean and median favourability of each group is in § C.2.

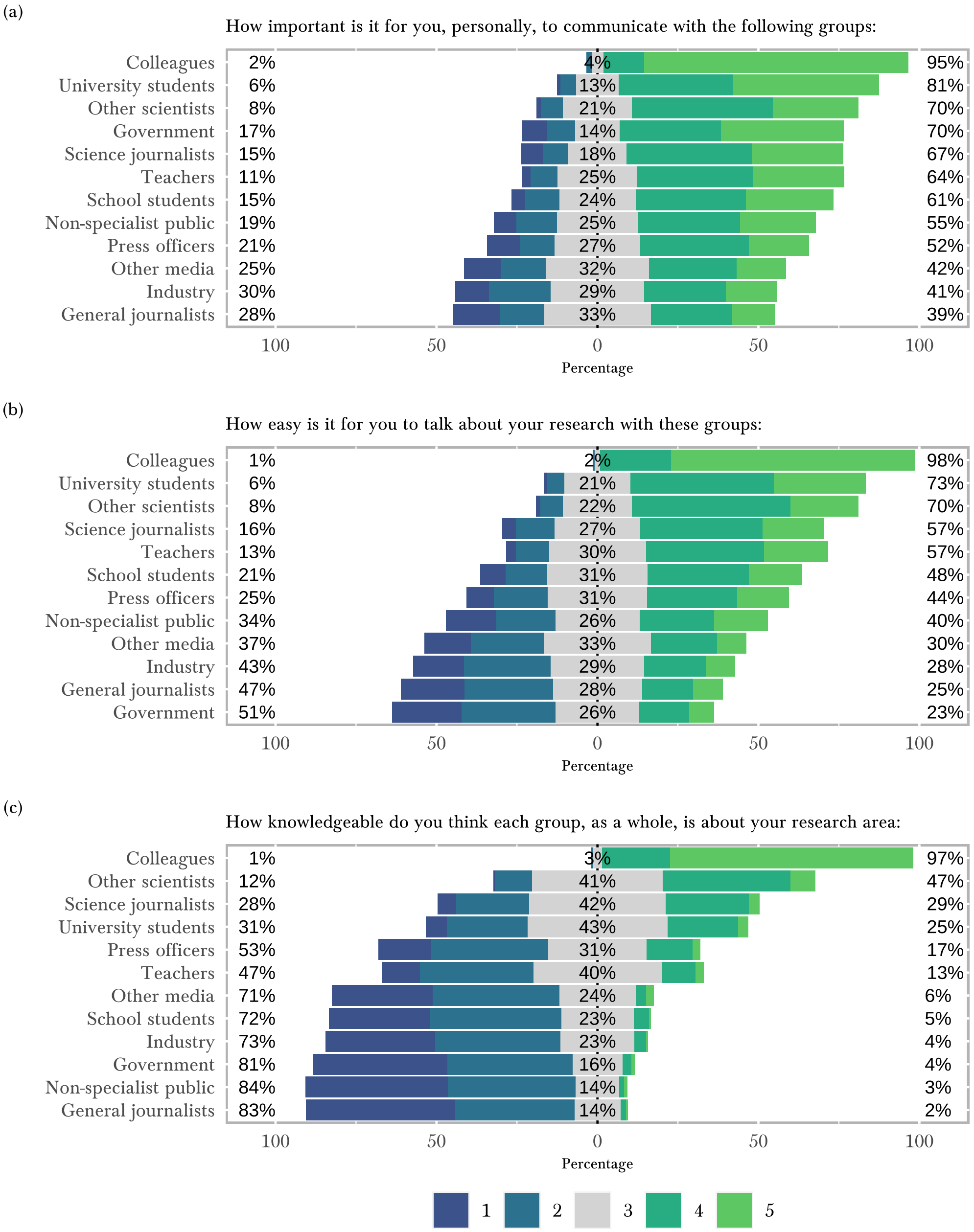

Figure 4.16: The ratings of the individual characteristics (a: importance, b: ease of communication, c: knowledge of particle physics) of each group

dissemination of science, to interested non-specialists and students, respectively. The "deficit model"-style literacy-enhancement aspect of communication therefore appears to be highly valued: one-way dissemination of either scientific information (media) or knowledge (education) is seen as an important element of communicating research outside one's immediate community. Both groups register similar ratings for importance and ease, although science journalists are seen by a considerably higher number of respondents as more knowledgeable about their research area.

The low rankings of groups such as government and industry deserve scrutiny. In a previous survey in the UK (Royal Society, Research Councils UK and Wellcome Trust, 2006), the importance of communicating with industry was ranked comparably with teachers and school students (grouped together) and science journalists, and considerably higher than the non-specialist public, while industry was ranked joint highest for ease of communication. However, the particle-physics community appears to see less value in participating in knowledge transfer. On the other hand, the same Royal Society survey showed that government was seen as an important audience but was also rated second-most in difficulty to communicate with, similar to the results of this research project, which also rates government as the most important non-academic group but lowest in ease of communication. Possible reasons for the rankings of these groups are presented in § 6.4.

Among media, specialist science journalists are clearly favoured over general reporters and other media, as also shown in prior research (Royal Society, Research Councils UK and Wellcome Trust, 2006; Science and Technologies Facilities Council, 2016), and it is particularly surprising how low general journalists are viewed overall in comparison with the other groups. However, Peters (2013, p.14107) showed that scientists "are mostly positive about their own encounters with the media". This was mirrored in the questions asking the respondents to rate the adequacy and accuracy of media coverage of science in general and particle physics in particular using *Agree–Disagree* Likert-type statements. The responses (Figure 4.17) suggest that the scientists would like to see more coverage of science in general but not necessarily more particle physics, and – while noting that coverage of neither is very accurate – feel that particle physics is covered more accurately than other sciences.

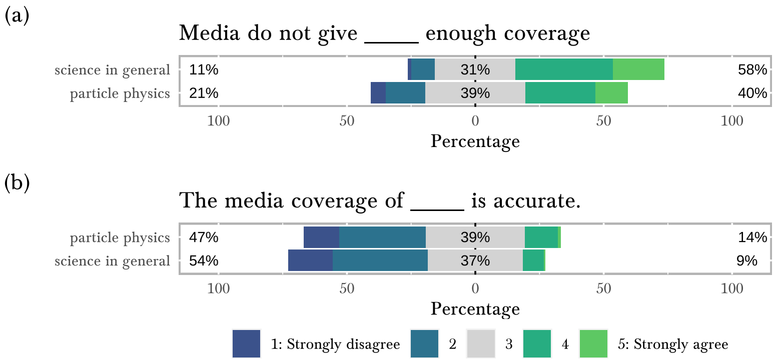

Figure 4.17: Adequacy and accuracy of science coverage in the media

4.2.4 Summary

The particle-physics community sees outreach as a duty and expresses positive views towards outreach and towards personal outcomes from outreach participation; the majority of the survey respondents have experience in outreach participation. However, these do not translate to a great deal of time spent doing outreach. Within the typology of science communication, “deficit model”-style dissemination approaches are more common. There exist both a strong pedagogical aspect to engagement, the outcome of which is the recruitment of the next generation of scientists, and a desire to inform the public of scientific progress via the specialist science-covering media. Dialogue or deliberation with – or indeed participation of – wider society is either not prioritised or outright dismissed: involving the non-specialist public is not seen as a priority or particularly important, and engaging with other stakeholders such as industry members or policy makers is not viewed favourably.

Public participation – in research itself or in decision-making on science-adjacent matters like the construction of research facilities – was discussed in greater depth in the personal interviews and is presented in the interview analysis (§ 5.2.2.2).

The data show that the feeling of being forced to defend one’s research and the possibility of oversimplifying one’s work were the strongest barriers (with nearly a quarter agreeing with the statements), while the scientists are generally quite confident in their ability to prepare themselves for outreach. However, none of the presented barriers were seen as such by even a simple majority of the respondents. This is unsurprising given the previous outreach experience of the majority of them.

We can see that while the scientists are not very strongly motivated by recognition, they value the communication experience they gain from outreach participation. They are also strongly driven by the idea that society stands to gain (knowledge) from their participation in outreach and that this benefits the wider research community itself. However, public-engagement ideals of collaboration with others, including non-specialist publics, are less valued and do not serve as important drivers for outreach participation.

4.3 Exploratory factor analysis

This section addresses **RQ2** and part of **RQ3** (namely the influence of funding bodies). Following the descriptive treatment of the survey responses, I performed a statistical analysis of the data. Specifically, exploratory factor analyses (EFA) were conducted on the data presented above, in order to identify the latent, underlying factors that describe the variety of responses received to the survey.

EFA provides a statistical description of the dataset of survey responses by identifying the covariance across the variables under study (i.e. the individual survey items). There exist a multitude of techniques for performing an EFA, each with its pros and cons, and each underpinned by certain assumptions about the dataset under scrutiny. Below, I recap each step of the analysis performed (full details, with references, can be found in the Methods chapter (§ 3.4.3)).

In this research project, first, three tests were conducted on each group of statements to determine their suitability for EFA: the Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy was calculated; Bartlett's test of sphericity was used to check for significant correlation in the data; and Cronbach's α was calculated, based on 50 iterations. Then the "parallel analysis" technique was used for ascertaining the number of factors, before the the EFA itself was performed. If the EFA showed only a single item for an individual factor, the number of factors obtained by parallel analysis was changed and the EFA was re-run until at least two items fell under each factor. Finally, the scores for each factory were obtained and used for further statistical treatment.

In the EFA for the benefits of outreach (§ 4.3.1) and perceptions about it (§ 4.3.2), the Likert items are analysed as individuals. They can also be conducted on scales obtained by combining individual survey items – as was the case when the audience favourability was calculated (§ 4.2.3) – and the EFA is consequently performed on the favourability scales rather than the individual ratings for importance, knowledge and ease of communication (§ 4.3.3).

4.3.1 Benefits

Table 4.9: Individual items for personal and societal benefits used for exploratory factor analysis

Var.	Statement
Personal benefits	
PB_exp	"It gives me experience in communicating my research."
PB_nam	"It gets my name known."
PB_fnd	"It attracts research funding."
PB_adv	"It advances my career."
PB_enj	"I get a feeling of enjoyment."
PB_sat	"It gives me job satisfaction."
PB_col	"It is an opportunity for others to contact me for collaborative purposes."
PB_sha	"It shapes the direction of my research or makes me think about it in new ways."
PB_btr	"It makes me a better scientist."
Societal benefits	
SB_kno	"The public gets better knowledge/understanding of science."
SB_jud	"It enables the public to judge scientific issues for themselves."
SB_liv	"It enables the public to make informed decisions about their lives."
SB_und	"It helps improve the understanding of what scientists do."
SB_opp	"There is less opposition to scientific research."
SB_edu	"More people enter science education/science careers as a result."
SB_pol	"Policy-makers are better equipped to make decisions."
SB_par	"Non-specialists can participate in scientific research."
SB_dec	"Society can make informed decisions about research funding."

As a reminder, there were 18 statements in total regarding benefits of outreach participation, nine to the scientist themselves and nine to society at large, as listed in Table 4.9. Descriptive statistics for each item of the dataset as well as a correlation plot of the items is in § C.3. The results of the three methods used to check if the data were suitable for a factor analysis were as follows:

1. The Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy suggests that the data seem appropriate for factor analysis (KMO = 0.85).
2. Bartlett's test of sphericity suggests that there is sufficient significant correlation in the data for factor analysis ($\chi^2(153) = 2451.76$, $p < .001$).
3. Cronbach's α, based on 50 iterations, is 0.86 (lower: 0.84; upper: 0.88).

Table 4.10: Factors: benefits

Results of factor analysis for benefits

Variable	ULS1	ULS3	ULS2	ULS4	h^2	u^2	com
PB_enj		**0.848**			0.727	0.273	1.088
PB_sat		**0.850**			0.728	0.272	1.004
PB_fnd				**0.584**	0.386	0.614	1.387
PB_adv				**0.636**	0.612	0.388	1.667
PB_nam				**0.421**	0.343	0.657	1.625
PB_exp		**0.482**			0.375	0.625	1.215
PB_col			**0.657**		0.530	0.470	1.232
PB_sha			**0.699**		0.593	0.407	1.188
PB_btr		**0.489**	**0.334**		0.497	0.503	1.768
SB_kno	**0.786**				0.660	0.340	1.253
SB_jud	**0.575**		**0.322**		0.548	0.452	1.789
SB_und	**0.758**				0.620	0.380	1.283
SB_opp	**0.529**				0.339	0.661	1.323
SB_edu	**0.555**				0.398	0.602	1.219
SB_pol	**0.668**			**0.338**	0.575	0.425	1.646
SB_dec	**0.721**				0.580	0.420	1.193
SB_liv	**0.582**		**0.429**		0.586	0.414	2.103
SB_par	**0.338**		**0.467**		0.399	0.601	1.963
SS loadings	3.837	2.378	1.906	1.376			
ULS1	1.000	0.403	0.440	0.298			
ULS3	0.403	1.000	0.452	0.291			
ULS2	0.440	0.452	1.000	0.412			
ULS4	0.298	0.291	0.412	1.000			

With the three methods demonstrating the suitability of the data for factor analysis, I proceeded with the factor analysis for the benefits of outreach participation. Parallel analysis predicted four factors for explaining the benefits dataset. The results of the EFA – performed to determine the variables associated with each of the four factors and the respective factor loadings – are shown in Table 4.10.[*] The EFA hints at a reclassification of the benefits as shown in Table 4.11.

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[*] The "ULS" in factor stands for "unweighted least squares", based on the method used to determine them.

Table 4.11: Benefits reclassified as factors

Factor	Name
ULS1	Societal benefits
ULS3	Personal benefits
ULS2	Benefits to research
ULS4	Career benefits

Table 4.12: Generalised linear regressions for the benefits of outreach

	Dependent variable:			
	Society	Personal	Research	Career
	(1)	(2)	(3)	(4)
age	−0.002	-0.02^{***}	-0.01^{**}	-0.01^{***}
	(0.004)	(0.004)	(0.004)	(0.004)
genderWomen	0.30^{**}	0.02	0.07	0.22^{*}
	(0.12)	(0.12)	(0.12)	(0.12)
experienceNo	-0.35^{**}	-0.53^{***}	0.31^{*}	0.20
	(0.17)	(0.17)	(0.17)	(0.17)
requiredNo	−0.20	−0.08	-0.37^{***}	−0.20
	(0.14)	(0.13)	(0.14)	(0.13)
requiredUncertain	−0.21	−0.21	−0.24	−0.06
	(0.15)	(0.15)	(0.15)	(0.15)
Constant	0.23	0.91^{***}	0.57^{**}	0.61^{***}
	(0.23)	(0.23)	(0.23)	(0.23)
Observations	367	367	367	367
Log Likelihood	−513.26	−504.82	−512.28	−505.64
Akaike Inf. Crit.	1,038.53	1,021.64	1,036.56	1,023.29
Note:	*p<0.1; **p<0.05; ***p<0.01			

Factor scores, calculated for each respondent for each of the factors, were then used to perform generalised linear regressions for the independent variables of age, gender, outreach experience and outreach requirements from funders, as shown in Table 4.12. The regression coefficients for all four factors bear a negative relationship with age: that is, as age increases, the regression coefficients decrease (albeit slightly) and the values for all but the first are statistically significant. The regression coefficients for the factors bear a positive relationship for women compared with men, suggesting women are more likely to value all four benefits of outreach participation, as compared to men, although only the relation to societal benefits is statistically significant.

For the independent variable of outreach experience, the regression coefficients for societal and personal benefits show a negative relationship for those without outreach experience while the coefficients for benefits to research and one's career show a positive relationship. That is, those without outreach experience are less likely to value societal or personal benefits and more likely to value benefits to research and their careers; the first three coefficients are statistically significant.

While the coefficients for all four factors bear a negative relationship with both those not required to do outreach and those who are uncertain about their outreach requirements, as compared to those who *are* required to participate in outreach by their research funders, only one of the coefficients is statistically significant. Those who are required to participate in outreach appear to value all four benefits more than those who either report not being required to do so or those who are not aware of their funders' outreach requirements.

4.3.2 Perceptions

The 29 statements chosen to evaluate perceptions about outreach are shown in Table 4.13. Descriptive statistics for each item of the dataset as well as a correlation plot of the items is in § C.3. Once again, the data were checked for suitability for factor analysis:

1. The Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy suggests that the data seem appropriate for factor analysis (KMO = 0.72).
2. Bartlett's test of sphericity suggests that there is sufficient significant correlation in the data for factor analysis ($\chi^2(406) = 2565.35$, p < .001).
3. Cronbach's α, based on 50 iterations, is 0.72 (lower: 0.68; upper: 0.76).

The three methods confirmed the suitability of the dataset for factor analysis. Parallel analysis predicted seven factors for the variables in the perceptions dataset. The results of the EFA – performed to determine the variables associated with each of the seven factors and the respective factor loadings – are shown in Table 4.14.[*] Note that two of the variables – `LO_nat` and `RF_LOC` – were not grouped with any of the factors. The EFA hints at a reclassification of the perceptions as shown in Table 4.15.

The factor scores for all seven factor were calculated for each respondent and used to perform generalised linear regressions for the independent variables as before,[†] as can be seen in Table 4.16. The first factor – societal obligation – had statistically significant regression coefficients for all independent variables but age. However, the results most worth remarking on are those for outreach experience. With the exception of perceptions of non-specialists, there are statistically significant differences between those with outreach experience and those without for all factors. The regression coefficients show that

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[*] The "ULS" in factor stands for "unweighted least squares", based on the method used to determine them.

[†] The entry with the incorrect age (100+) was removed from this statistical treatment, as explained in § 4.1.2.

Table 4.13: Individual items for perceptions about outreach used for exploratory factor analysis

Var.	Statement
Moral norms	
MN_dut	"I have a duty as a scientist to take part in outreach activities."
MN_tax	"It is important for scientists to take part in outreach activities because taxes from citizens fund research."
Perceived behavioural control	
BC_que	"I feel confident that I could answer questions asked by the public."
BC_mat	"I feel confident that I could prepare the necessary materials to participate in an outreach activity."
BC_inv	"It is easy for interested scientists to get involved in outreach."
BC_pro	"Scientists should get help from professional communicators when communicating their findings to the non-specialist public."
BC_skl	"Scientists do not have the communication skills for discussing their work with the non-specialist public."
Perceptions of non-specialist publics	
NS_und	"In general, people have little understanding of what scientists do."
NS_kno	"The public lack knowledge/education about the facts of science."
NS_app	"The general public does not appreciate how science affects them."
NS_int	"There is a lack of interest in science among the general public."
NS_sci	"Scientists underestimate how knowledgeable the general public is about science."
Environmetal constraints	
EN_tim	"Participating in outreach takes too much time away from research."
EN_mon	"I would participate in outreach activities if there was money to support participation."
EN_com	"Commercial barriers prevent greater participation in outreach."
Language of outreach	
LO_nat	"I will only participate in an outreach activity if it is in my native language."
Subjective norms (the "Sagan effect")	
SE_col	"My colleagues would approve of my taking part in an outreach activity."
SE_ins	"My home institution generally supports scientists who take part in outreach activities."
SE_bad	"Taking part in an outreach activities could be bad for my career."
SE_ser	"I would not be taken seriously as a scientist by the public if I participate in outreach."
Perceived suitabililty of research	
SR_def	"I might feel forced to defend my research when participating in outreach."
SR_sim	"To communicate with the public, I have to overly simplify my work, which reduces its scientific correctness."
SR_com	"My research is too complex for an outreach activity."
Outreach plans and research funding	
RF_sup	"Funding bodies should provide support for scientists to communicate their research to the non-specialist public."
RF_gra	"When applying for grants, scientists should be required to provide details on how their research will be communicated to the wider society."
RF_loc	"When building new research facilities, the local community should be involved in the decision-making process."
Role of culture and policy	
RC_cul	"In the country of my institute/university, outreach and public communication are part of the academic culture."
RC_soc	"In the country of my institute/university, society expects scientists to discuss their work in public (e.g. through media interviews, public lectures etc.)."
RC_pol	"Government policy encourages outreach."

Table 4.14: Factors: perceptions

Results of factor analysis for perceptions

Variable	ULS2	ULS5	ULS6	ULS3	ULS4	ULS1	ULS7	h^2	u^2	com
MN_dut	**0.628**							0.580	0.420	1.338
MN_tax	**0.666**							0.457	0.543	1.195
BC_que						**0.910**		0.737	0.263	1.034
BC_mat						**0.786**		0.811	0.189	1.206
BC_inv	**0.304**							0.278	0.722	3.295
BC_pro							**0.838**	0.644	0.356	1.313
BC_skl							**0.374**	0.239	0.761	1.895
NS_und				**0.818**				0.641	0.359	1.154
NS_kno				**0.686**				0.484	0.516	1.612
NS_app				**0.629**				0.432	0.568	1.193
NS_int				**0.348**				0.293	0.707	2.890
NS_sci				**-0.345**				0.208	0.792	2.185
EN_tim			**0.427**					0.348	0.652	1.545
EN_mon			**0.306**					0.135	0.865	1.862
EN_com			**0.614**					0.344	0.656	1.335
LO_nat								0.065	0.935	2.573
SE_col		**0.993**						0.800	0.200	1.346
SE_ins		**0.596**			**0.386**			0.591	0.409	1.972
SE_bad		**-0.672**						0.449	0.551	1.528
SE_ser			**0.645**					0.583	0.417	1.654
SR_def			**0.447**					0.193	0.807	1.184
SR_sim			**0.484**					0.200	0.800	1.251
SR_com			**0.415**					0.304	0.696	1.709
RF_sup	**0.719**							0.512	0.488	1.207
RF_gra	**0.735**							0.521	0.479	1.138
RF_loc								0.221	0.779	4.849
RC_cul					**0.741**			0.671	0.329	1.146
RC_soc					**0.809**			0.644	0.356	1.131
RC_pol					**0.518**			0.278	0.722	1.106
SS loadings	2.216	1.913	1.941	1.823	1.868	1.77	1.13			
ULS2	1.000	0.252	-0.078	-0.167	0.252	0.524	0.182			
ULS5	0.252	1.000	-0.351	0.024	0.310	0.322	-0.308			
ULS6	-0.078	-0.351	1.000	0.260	0.061	-0.303	0.309			
ULS3	-0.167	0.024	0.260	1.000	0.016	-0.128	-0.116			
ULS4	0.252	0.310	0.061	0.016	1.000	0.281	-0.071			
ULS1	0.524	0.322	-0.303	-0.128	0.281	1.000	-0.028			
ULS7	0.182	-0.308	0.309	-0.116	-0.071	-0.028	1.000			

Table 4.15: Perceptions reclassified as factors

Factor	Name
ULS2	Societal obligation
ULS5	The Sagan effect
ULS6	Perceived constraints
ULS3	Perceptions of non-specialists
ULS4	Role of culture and policy
ULS1	Confidence in preparation
ULS7	Perceptions on communications ability

Table 4.16: Generalised linear regressions for the perceptions about outreach

	Dependent variable:						
	Societ.	Sagan	Constr.	Non-spec.	Culture	Confid.	Comms.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
age	0.004	−0.005	−0.01	-0.01^{*}	0.01	0.001	0.0004
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
genderWomen	0.27^{**}	−0.04	0.04	−0.05	0.16	0.05	−0.06
	(0.12)	(0.13)	(0.12)	(0.13)	(0.13)	(0.12)	(0.13)
experienceNo	-0.55^{***}	-0.65^{***}	0.70^{***}	−0.01	-0.28^{*}	-1.06^{***}	0.35^{**}
	(0.16)	(0.17)	(0.16)	(0.17)	(0.17)	(0.16)	(0.17)
requiredNo	-0.47^{***}	0.13	-0.23^{*}	0.06	-0.24^{*}	−0.18	−0.22
	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)	(0.14)
requiredUncertain	-0.40^{***}	0.04	0.02	0.14	0.19	−0.23	-0.27^{*}
	(0.15)	(0.16)	(0.15)	(0.16)	(0.15)	(0.15)	(0.15)
Constant	0.19	0.22	0.23	0.24	−0.24	0.23	0.17
	(0.23)	(0.24)	(0.23)	(0.24)	(0.24)	(0.23)	(0.24)
Observations	355	355	355	355	355	355	355
Log Likelihood	−484.78	−500.31	−486.02	−502.64	−491.64	−479.22	−495.07
Akaike Inf. Crit.	981.57	1,012.62	984.04	1,017.27	995.29	970.45	1,002.14
Note:					*p<0.1; **p<0.05; ***p<0.01		

those without outreach experience are less likely to feel a sense of obligation to society to participate in outreach, less likely to believe they have institutional support for outreach, more likely to cite constraints as reasons for not doing outreach, less likely to believe the socio-cultural reasons to participate in outreach, less likely to feel confident about participating in outreach and more likely to believe that communications skills are barriers.

4.3.3 Audiences

Table 4.17 shows the 12 target groups chosen for the evaluation of their favourabilities. Descriptive statistics for each item of the dataset as well as a correlation plot of the items is in § C.3. The suitability of the dataset for factor analysis was determined as, as before:

1. The Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy suggests that the data seem appropriate for factor analysis (KMO = 0.91).
2. Bartlett's test of sphericity suggests that there is sufficient significant correlation in the data for factor analysis ($\chi^2(66) = 2620$, $p < .001$).
3. Cronbach's α, based on 50 iterations, is 0.91 (lower: 0.89; upper: 0.92).

Table 4.17: Individual items for favourability of audiences used for exploratory factor analysis

Var.	Statement
fav_col	Your colleagues and collaborators / other people in your research field
fav_osc	Other scientists or experts outside your research field
fav_prs	Press officers at your university/institute
fav_tch	Teachers
fav_uni	University students
fav_stu	School students / pupils
fav_gen	General journalists
fav_sci	Science journalists
fav_omd	Other media (writers, documentary makers)
fav_gvt	Government / politicians / policy makers
fav_ind	Industry / corporate sector / private companies
fav_nsp	Non-specialist public

Table 4.18: Factors: audiences

Results of factor analysis for audiences

Variable	ULS1	ULS2	ULS4	ULS3	h^2	u^2	com
fav_col				**0.563**	0.321	0.679	1.009
fav_osc			**0.604**	**0.389**	0.512	0.488	1.736
fav_prs	**0.654**				0.628	0.372	1.188
fav_tch		**0.616**			0.593	0.407	1.138
fav_uni		**0.771**			0.636	0.364	1.136
fav_stu		**1.027**			0.880	0.120	1.046
fav_gen	**0.766**				0.758	0.242	1.069
fav_sci	**0.928**				0.734	0.266	1.144
fav_omd	**0.871**				0.731	0.269	1.014
fav_gvt	**0.690**				0.619	0.381	1.257
fav_ind			**0.469**		0.478	0.522	1.852
fav_nsp		**0.556**			0.527	0.473	1.285
SS loadings	3.429	2.495	0.9	0.593			
ULS1	1.000	0.693	0.634	0.028			
ULS2	0.693	1.000	0.598	0.133			
ULS4	0.634	0.598	1.000	0.077			
ULS3	0.028	0.133	0.077	1.000			

With the three methods confirming the suitability of the dataset for factor analysis, parallel analysis was performed and predicted three factors for the variables in the perceptions dataset. However, the resulting EFA showed only one item for the third factor (namely `fav_col`). As a result, EFA was performed for four factors, resulting in the factor classification shown in Table 4.18.[*] The EFA hints at a reclassification of the perceptions as shown in Table 4.19.

Table 4.19: Audiences reclassified as factors

Factor	Name
ULS1	Groups for dissemination
ULS2	Groups for education
ULS4	Groups related to research
ULS3	Peer groups

Table 4.20: Generalised linear regressions for the audiences for communication

	Dependent variable:			
	Dissem.	Educate	Related	Peers
	(1)	(2)	(3)	(4)
age	0.02^{***}	0.02^{***}	0.02^{***}	-0.01^{***}
	(0.004)	(0.004)	(0.004)	(0.004)
genderWomen	0.01	−0.17	0.001	0.07
	(0.11)	(0.12)	(0.12)	(0.12)
experienceNo	−0.18	-0.63^{***}	-0.31^{**}	−0.22
	(0.15)	(0.16)	(0.16)	(0.17)
requiredNo	-0.35^{***}	-0.30^{**}	-0.36^{***}	−0.02
	(0.12)	(0.12)	(0.12)	(0.13)
requiredUncertain	-0.32^{**}	−0.21	−0.07	−0.12
	(0.14)	(0.14)	(0.14)	(0.15)
Constant	-0.74^{***}	-0.37^{*}	-0.76^{***}	0.56^{**}
	(0.21)	(0.21)	(0.21)	(0.23)
Observations	390	390	390	390
Log Likelihood	−519.37	−524.71	−525.21	−549.66
Akaike Inf. Crit.	1,050.75	1,061.42	1,062.43	1,111.33
Note:				$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

After this, factor scores were calculated for each respondent for each of the four factors and, using them as the dependent variables, generalised linear regressions were performed,[†] the results of which are shown in Table 4.20. Across all groups, the regression coefficients with age bear a small but statistically significant relationship, although the relationship is negative with the "Peers" factor. Regression coefficients for all factors bear a negative relationship with outreach experience; those who have not participated in outreach are less likely to value all target groups, but the relationships with only the second and third factors are statistically significant. For those who report not being required to do outreach, the negative regression coefficients for the first three factors are statistically significant.

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[*] The "ULS" in factor stands for "unweighted least squares", based on the method used to determine them.

[†] The entry with the incorrect age (100+) was removed from this statistical treatment, as explained in § 4.1.2.

This would imply that those who are required to do outreach are more likely to value communication aimed at media and government, those in education and those related to research.

4.3.4 Summary

Exploratory factor analysis allows us to determine how the attitudes described in § 4.2 vary with age, gender, outreach experience and research funders' requirements to do outreach.

The most crucial result of the exploratory factor analysis concerns outreach experience. Across nearly all the factors in all three datasets, those with outreach experience held more positive views compared with their counterparts who had never participated in outreach. Respondents who reported being required to do outreach by their research funders were more likely to be positive in their views compared with their colleagues who reported not being required to participate in outreach. However, those who reported not knowing their outreach requirements were more positive for many of the perceptions of outreach, even though the relationships were not statistically significant. Age played a role in views on the benefits of outreach, with those older more likely to value the benefits to themselves, to research and to their careers, and in the favourability of all audience groups. Gender was not significant for the majority of factors, although women were more likely to view the benefits to both society and their careers more positively in a statistically significant way.

These results should be considered not in isolation but in conjunction with the qualitative results presented in Chapter 5.

Chapter 5

Interview analysis

In this chapter, I present the results of a qualitative analysis of the interview data collected for this research. I first describe the demographics of the interviewees (§ 5.1), followed by an analysis of the themes that were identified from the dataset of interview transcripts (§ 5.2), and the summary of the analysis (§ 5.3). The analysis seeks to address the first, third and fourth research questions of this thesis (**RQ1**, **RQ3** and **RQ4**):

- **RQ1**: "What are the attitudes towards outreach within the particle-physics community, including the motivations for – and barriers against – participating in outreach activities?"
- **RQ3**: "How, if at all, are these attitudes influenced by (a) differing expectations from funding bodies and (b) being part of large, international collaborations?"
- **RQ4**: "Are participatory paradigms present in the discourse concerning outreach within the particle-physics community, and what is the perceived relevance of the research to the everyday lives of non-specialists?"

The interviews, which were all conducted in English, were transcribed and coded for thematic analysis, as discussed in the § 3.6.

5.1 Demographics of interviewees

The 19 interviewees were chosen by purposive sampling, as described in § 3.5.2. As a reminder, only one of the interviewees did not have any outreach experience, and all 16 from CMS had responded to the survey. Table 5.1 shows a summary of the interviewees by affiliation, gender, age group (as defined

Table 5.1: Demographics of the interviewees

Affiliation	N	Gender	N	Age group	N	Scientist type	N
CMS	16	Men	13	Senior	10	Physicist	16
ATLAS	3	Women	6	Young	9	Doctoral Student	3

Table 5.2: Country of affiliation of the interviewees

Country of affililation	N
CERN	5
USA	5
Belgium	3
Switzerland	1
Germany	1
Spain	1
Finland	1
India	1
Italy	1

in § 4.1.2) and role/activity. Table 5.2 shows their respective countries of academic affiliation (with CERN kept separate).

As mentioned in § 3.6, the interviews are not analysed with regards to the characteristics of the scientists (such as age and gender). Therefore, these are not explicitly discussed in this chapter. All the (sur)names below are pseudonyms, to protect the identities of the interviewees.

5.2 Themes identified

Six key themes were identified through a thematic analysis performed on the transcripts of the 19 interviews. The themes can further be paired into three categories, in that they refer to (1) “publics”, (2) “scientists” and (3) ”research” respectively:

- Public engagement has diverse meanings (*publics*, § 5.2.1)
- Involvement of non-experts is non-trivial (*publics*, § 5.2.2)
- Access enhances participation (*scientists*, § 5.2.3)
- Communicating improves communication (*scientists*, § 5.2.4)
- Particle physics is not relevant to people’s lives (*research*, § 5.2.5)
- Science is culture (*research*, § 5.2.6)

Illustrative examples from the transcripts provide evidence for each of the themes, below,* along with developed (intermediate) thematic maps showing the evolution of the final themes.

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*All emphasis indicated by bold letters in the selected quotes has been added by researcher.

Table 5.3: Illustrative examples taken from each interviewee per theme

Interviewee	Meanings	Non-experts	Access	Comms.	Relevance	Culture	Total
A. Smith	3	3	1	3	1		**11**
C. Davies	1	2	3	2	1		**9**
H. Roberts	1	2	4		2		**9**
J. Robinson		1	2	3	2	1	**9**
P. Wood	2	2	1		3	1	**9**
R. Jackson	1	2	3	2		1	**9**
B. Jones	2	2	3			1	**8**
S. Clarke	3	2	1	2			**8**
N. Green	1	2		2	2		**7**
E. Brown	1	1	1	1	2		**6**
O. Lewis	1	2		1	2		**6**
G. Evans	1	1	1		1	1	**5**
M. Edwards	1	2	1			1	**5**
K. White		1	1		1	1	**4**
F. Wilson	1	1			1		**3**
L. Hughes	1		2				**3**
D. Williams			2				**2**
I. Wright	1		1				**2**
Q. Harris	1	1					**2**
Total	**22**	**27**	**27**	**16**	**18**	**7**	**117**

5.2.1 Public engagement has diverse meanings

In the survey that made up the first phase of this research, the term “outreach” was used in lieu of “public engagement” after being defined in a broad, general sense for the respondents at the start of the questionnaire. However, in order to explore what forms public engagement took (or could take) within the particle-physics community – and in particular whether participatory paradigms are present in the discourse (see **RQ4** above) – the first question that the interviewees were asked required them to reflect on what the term “public engagement” meant to them.

> *“Oh, that I participate with (sic) outreach events. If there is a big event for example in [my hometown], and we have a tent there with exhibitions, I would be there and talk to people and tell them our story. Also I go to conferences like [redacted], this is a big event for the Internet nerds, and give a story there. So [public engagement] means having outreach with other people.”* (I. Wright)

Some, like I. Wright above, likened it to outreach. Not all the interviewees did so, however, and these comments comprise the theme “Public engagement has diverse meanings”. There are four aspects to this theme.

Figure 5.1: Developed thematic map for the theme "public engagement has diverse meanings"

5.2.1.1 One-way dissemination

As demonstrated in the survey analysis (Chapter 4), a majority of the CMS scientists hold views towards public engagement that are characteristic of "deficit model"-style thinking; namely, of attitudes more common to the "scientific literacy" or "public understanding of science" paradigms. These attitudes were also present in the interviews, either mentioned explicitly or implied. Take for instance B. Jones:

> *"[P]ublic engagement deals with students, it deals with the general public, it deals with the media, it deals with decision makers and all of these are important audiences."* (B. Jones)

While enumerating the various groups that one might involve in a public-engagement activity, the above interviewee refers to these groups as audiences: vessels meant to receive information being transmitted by scientists.[*] It implies an underlying conceptualisation of science communication as a

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[*] The previous chapter also refers to "audience groups" targeted for communication (§ 4.2.3), but this terminology was chosen

one-way process. This position becomes clearer as the interviewee continues:

> *"[W]ithin the science realm, different people... they are different sub-groups that they focus on. A lot of people focus on the decision makers because they matter. [...] Personally, my focus is on the broad public and the idea being is that if I can help* ***modify the understanding of the public or the degree to which the public embraces science*** *it will make the other jobs easier."* (B. Jones)

Some interviewees chose to examine the meaning of the individual words making up the term "public engagement", with P. Wood describing engagement as a proactive step:

> *"[W]ell the public is the broad, wide set of people who are not experts, who are not practitioners. Engagement in my view means going there and talking to them without expecting that they will come to you."* (P. Wood)

However, the objective expressed – namely, to create empathy and allay fears – grounds this initiative-taking once again in improving the public understanding of science, as the interviewee elaborates:

> *"[I]t's not really explain or teach, it's sharing what we do, why we do it, in order to* ***create some sort of empathy*** *in a sense, so that* ***people can better understand*** *that we don't all use white lab coats, we are not setting out to destroy the world, that sort of thing. There are many preconceptions out there and I think that engaging is, again, not expecting people to come to you and ask, 'Are you really destroying the world?' But rather go and say what you are doing and through that process sort of* ***making it obvious that the world's not being destroyed.****"* (P. Wood)

Others similarly discussed the desire to improve understanding of science and the joy they get from observing that understanding take hold.

> *"I think it means talking to people about what I do specifically and putting it into terms they understand. So, that usually means like connecting it in a sort of linear way to something that they know. Like a logical step-by-step way or by you know using analogies that they can grasp."* (C. Davies)

> *"I think it gives you pleasure when you understand something for the first time and then when you are able to communicate that to somebody else. [...] And then* ***the spark you see in the eyes of the***

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explicitly because it was used in the Royal Society survey (Royal Society, Research Councils UK and Wellcome Trust, 2006).

> ***lay public when they understand very complicated concepts that we scientists are studying, I think that's brilliant.*"** (E. Brown)

On the one hand, scientists spoke of increasing public understanding of particle physics specifically; on the other, they also addressed the understanding and appreciation of science more generally, with multiple interviewees mentioning the scientific method. For example, S. Clarke spoke about the importance of sharing information about the scientific process:

> *"I think that there's much more than the information aspects of particle physics, there's also* ***what's behind it, scientific process, how we do things, how we're super critical about our measurements.*** *"* (S. Clarke)

The scientists see themselves as being in a privileged position and are keen to share the wonders they encounter, as S. Clarke continues:

> *"[B]esides the scientific method, one of the things that's interesting about what we do is* ***we look at a world which is completely different than what most people usually see****, well, all of us usually see. We see apples falling down and we understand macroscopic… stuff. But the world is completely different and we get this privilege of learning about quantum tunnelling and entanglement and all these weird things and while people might see headlines with that and they don't understand… and* ***I'd like to share that cause that's an awesome experience, to understand that the world is quantum mechanical when it's really small or that it's relativistic when it's really fast****. And so I like to share that pleasure with the world. It helps everyone to think differently."* (S. Clarke)

The idea that increasing society's understanding of the scientific method is beneficial in itself was reinforced by G. Evans:

> *"[…] The other part is* ***the experiment and the scientific method****, the fact that to extract conclusions you have to think beforehand what you want to do and to develop a procedure and to look at the data, the universe, the nature and draw your conclusions in a consistent way avoiding the prejudices. And discussing with people who may contradict what you are trying to conclude. And this is not common in society. Typically you try to impose your feelings or beliefs or whatever,* ***so somehow conveying this idea of the scientific method or maybe transposing it other aspects of the daily life of society would improve let's say the quality of our society.*** *"* (G. Evans)

These attitudes call back to ideas of scientific literacy and notions concerning a knowledge deficit. Science – or scientific thinking – is also depicted as a net positive for society and as something that resides outside of social influences. At the same time, the interviewees did not frame the matter as purely communicating facts and convincing their "audiences" of their work's value; they focused on their desire to share the joys they themselves experience through their scientific pursuits.

5.2.1.2 Transactional

Next, many of the interviewees described public engagement as transactional, something done because research is (mostly) funded by taxes. The purpose of participating in public engagement is then to be held publicly accountable to those contributing financially to research.

For example when asked to explain what public engagement meant to them, R. Jackson said:

> *"That the job of a scientist is not only doing science but helping everyone understand what the scientist is doing, the scientist works for [the] community and not really… **it's public property**, science is not someone's property."* (R. Jackson)

Some scientists therefore appear to be motivated to participate in public engagement to justify the tax-funded money being spent on research. R. Jackson continued, with a reference to the publicly-funded nature of research:

> *"Oh, so it's also public money that we use, so **everyone should be able to understand why we spend money on science**, also how the money is used, so what we are doing exactly and why we are doing it, so that we… Many people think that we waste money in science and **if we want them to think otherwise then they need to understand what we do**."* (R. Jackson)

Both A Smith and L Hughes researchers expressed similar thoughts:

> *"Public engagement, I never thought of that, but if I have to figure out a meaning, it probably means that public research is done using public money, so we have to communicate what we're doing back to the public, **not only as a means to making sure that we get this money in the future, but also on a moral basis**. So we are spending the public's money, so we have to be engaged to communicate something at least [of] what we are doing."* (A. Smith)

> *"Public engagement according to me is trying to give the people who do not have a technical knowhow a flavour of what you are doing because from [my country's] perspective, **the money for research***

> ***solely comes from the government and it's the tax payers' money.*** *So I think the general public has a right to know what the money is being spent for. And also because what we do are pretty cool."* (L. Hughes)

This notion of "giving back" to society in exchange for their financial support of research aligns with the moral norms explored in the survey analysis (§ 4.2.2.1). Separately, A. Smith saying they had not thought about the term "public engagement" before may have to do with the fact that different countries and cultures use different terms to refer broadly to science-communication activities. In English, they may refer to it as "outreach" and in several European languages the preferred term translates to "dissemination" or "public relations".

5.2.1.3 Education and recruitment

For many scientists, especially those based at universities and who have teaching responsibilities, public engagement is seen a tool for recruitment and this was something noted in a number of the interviewees' comments. When asked to contrast the outreach efforts of their home institution with that of CERN, R. Jackson offered that the distinct approaches were a consequence of both budget and vision:

> *"For my home institute it is really mostly towards students, to have students go and study physics. So it's more to [recruit], really, students than to, I don't think the aim is outreach, the aim is having more students."* (R. Jackson)

They elaborated on the influence of available budgets in contrasting the kinds of activities CERN as an institution organises and those organised by individual university departments:

> *"CERN has a lot of budget compared to individual [departments]… so, they can make big projects and they can also communicate to a larger scale. And I think at least in [my country] our outreach was more towards high-school students […]. I think it is the easiest way to do it if you don't have a large budget, you don't have many people working on this, you just have the list of [teachers], so you always send to the same [teachers].* ***So it's more just like giving some more lessons because it doesn't cost anything."*** (R. Jackson)

The desire to educate people about not just particle physics but about science more generally was a recurring topic, with the explicitly stated goal being the recruitment of the next generation of scientists. Many of the interviewees expressed the desire to ignite the spark of interest in science to inspire young people to take up physics and related studies. N. Green hoped specifically to establish a connection with those who come from families without strong academic backgrounds:

> *"[T]his can trigger the attention and the interest of young guys that maybe are not coming from an environment where their family necessarily support them for something that is research work, because typically the family, they want to push the youngster to go to the university, if they have the money to go to university, to be lawyers, engineers, this sort of things where you are making back the money that was used to support you. [. . .] But from time to time, the only way to trigger the interest of the young people at public level who have the capacity of contributing to the research of mankind,* ***is to tell them that there is this possibility****."* (N. Green)

F. Wilson, who has not participated in outreach before, echoed this perspective, acknowledging how popular science books inspired them as a teenager to take up a career in science later on in life:

> *"I think this is interesting to let people become interested in particle physics. I remember reading this, how do you say, books about science when I was a teenager, written by Asimov who was a very good writer about science as well, and getting very interested about biology and physics. So I think this is one of the main reasons why it's important for us as a community to try and get people engaged and interested in what to do."* (F. Wilson)

Yet others leaned on the pedagogic element, emphasising their role in working with teachers to bring particle physics to the classroom. When asked if members of wider society could play a role in particle-physics research, O. Lewis suggested that teachers might contribute to "the success of particle physics", by serving as "multiplicators":

> *"So we have teacher programmes at CERN and we have about 1000 teachers per year are coming to CERN from various nationalities. And they have a one-week course here. And they get a glimpse of particle physics.* ***And these are multiplicators. So really they are our ambassadors, you can call them****. [. . . O]ne teacher has a class of 20–30 hopefully interested high-school students and so if they can multiply what they have learnt and to give their enthusiasm, most of them are enthusiastic when they leave [CERN]. And if they get one or two in their class, then that's already good. Say they get the particle physics virus a little bit, yeah."* (O. Lewis)

For A. Smith, teachers were clearly the most important community to focus on for activities such as on-site visits:

> *"So to me, we have many visitors at CERN, and to me the most important is physics teachers, because* ***they understand most of what we are doing and they educate the young generation who can continue this business****. That's for me the main purpose. And the second purpose is to entertain the public, the tourists. But they can also spread certain things, hopefully. But teachers are the most important to me."* (A. Smith)

A. Smith went so far as to openly advocate favouring teachers over other groups in outreach activities:

> *"Maybe this is against some policy, but even more importantly, when this large amount of tourists come in, I'm not sure we should go the extra mile for them.* ***I would rather make priorities and accept physics teachers and then students, and then everybody else****. Maybe that is done already, I don't know. But it cannot happen that physics teachers cannot come in because of lack of time slots."* (A. Smith)

5.2.1.4 Conversation

A minority of the interviewees defined engagement as necessarily two-way. Q. Harris explained how being involved with diplomacy activities was influential in changing their perceptions, going from asking why funding agencies didn't think particle physics was worth funding to recognising that scientists may not be aware of what various groups in society are interested in:

> *"[. . .] I think I spent two years, three years ago, [. . . on] a scientific fellowship where we were engaging in diplomacy. And I learned that diplomacy is a completely different thing than what I thought it was, and that if we want to actually make sure that our scientific information is out there we have to be communicating with the public all the time. So it's gone from this narrow thing of 'Why don't you fund me?' to 'Most people have no idea what we know.' [. . . W]e were trying to engage with actually religious communities to try and. . . . And I had no idea that they were actually interested in protecting against climate change, and that's 'cause* ***I think scientists actually have no idea what the public is actually interested in****. So a lot of it is* ***has gone from me wanting to promote what we do for my purposes to me finding out what other people are actually interested in and how we can help them****."* (Q. Harris)

S. Clarke also explicitly spoke of two-way engagement.

> *"[E]ngaging to me means more discussing with whoever it is and getting ideas from them as well as*

> *sharing ideas with them. [...] **I like to hear what the concerns are of the public about what we're doing and try to answer questions but also learn from them.**"* (S. Clarke)

M. Edwards agreed, noting that one-way communication misses the point of public engagement:

> ***"You would like to engage as a scientist to get your knowledge transfer or utilise your knowledge for the society but you also like to engage the society in your research. So it goes in two ways.*** *Whenever I think it is only a one-way communication, I think you missed the point. [...] So, it's a two-way process, and I think whenever you have the full two-way, both ways, implemented I think then you succeed."* (M. Edwards)

While H. Roberts also highlighted the two-way nature of engagement, the idea of a "conversation" is nonetheless framed as two-way asymmetrical (Grunig and Hunt, 1984), with the examples of engagement falling closer to the "dissemination" end of the spectrum:

> *"Well it's a two-way interaction between science and the public where the public could be anybody who is essentially not science. And engagement implies that they're both interacting, it's not a one way thing where you send out news or something but you actually get them to participate in some way. **For example they attend an event, they do an educational exercise or something like that.** I think the key thing is it's two way I would say, the engagement. And if it's not two way you haven't really engaged them, it's just a lecture or a monologue or something like that."* (H. Roberts)

So, although most interviewees used language associated with more traditional views on public engagement, with unidirectional "from-us-to-them" notions holding sway, a small number of the interviewees spoke about the importance of two-way communication and "listening" to the views and concerns of wider society when participating in an outreach activity. One can therefore conclude that there is evidence for notions of two-way engagement percolating through the community.

5.2.2 Involvement of non-experts is non-trivial

Despite some of the positive views expressed towards engagement in the last section, most interviewees expressed reservations to varying degrees about non-experts from wider society playing a role in particle-physics research, regarding both direct participation and indirect involvement through oversight. Where they entertained the idea of public participation in research, many – with some notable exceptions – limited it to passive participation via resource sharing or dissemination of information about particle physics on behalf of scientists.

Figure 5.2: Developed thematic map for the theme “involvement of non-experts is non-trivial”

5.2.2.1 Participation

In response to the question on whether wider society could play a role in research, many suggested that volunteers could provide computing resources via the LHC@home project. This project allows interested people to run LHC-related computational tasks on their personal devices, thus helping research.

> *“Obviously society might help us if they all of them provide access to their computers – obviously we have much more computers around – I think these kind of projects are being done, some of them are successful, but that’s the very practical way of helping us.”* (M. Edwards)

> *“I like these LHC@home stuff, using people’s computer networks to contribute, a lot. Back when I was a first-year college student, I definitely ran SETI@home on my college laptop and I thought that that was really cool.”* (C. Davies)

Expressing positive views around these types of projects, E. Brown recounted the CERN press office calling them to ask about a high-school student in their home country who had won a state-level prize for volunteering computer time for LHC@home:

> *"[T]here are so many of these initiatives where everyone can engage and participate. And believe me, just participation can give you goosebumps. [...] So I think it's just an example to show you that anyone can participate in what we are doing and what impact it can have in the larger society, larger audience."* (E. Brown)

For J. Robinson, preparing the tools to enable interested parties to join projects like LHC@home results in scientists interacting with those outside their field of research:

> *"And for us it also requires some explanations and we have to interact also to motivate that, to let them know how it is useful and what they are really running on their machines.* ***So the fact that it helps in the communication is good as well.*** *[...] The fact that people get interested and do use their computers' spare [computing] cycles to help CERN or other particle-physics facilities makes them feel like part of the project."* (J. Robinson)

It is important to note that participation in LHC@home is passive, with computers performing the computation in an entirely automated way once the user sets up the software and its operating parameters. Related fields like astronomy have projects like Galaxy Zoo that rely on crowd-sourcing to identify features in photos of space. As A. Smith explains, particle physics has a much larger number of "snapshots" of particle collisions, which are best analysed by computers:

> *"Very hard question. In other fields of science they do, like astronomy. They find very fancy objects in the sky, which is hard to find in a computer code. And here the problem is we have many more pictures than astronomical observations, so to look through them by eye is not so easy and also not so easy to find something that you see immediately.* ***So you need at least some mathematical background to contribute I believe."*** (A. Smith)

Thus, the most cited avenue for members of wider society to participate in research is in fact to provide scientists with resources (computing) at cost to themselves (associated utilities bills).

Others suggest that the role non-experts can play is in amplifying the messages that come from scientists and by encouraging their children to take up studies and careers in research.

> *"Not in the research directly, I would say. But in communicating the results. This of course is possible and should be done. It is done. It is done by communicators, who are sometimes, not often, particle physicists."* (O. Lewis)

> *"They can play a role to the extent they allow their sons and daughters to do research. That is the main role. If they allow the youngest [unclear] in the right direction so they played a role. Probably this is the most important part."* (N. Green)

Providing a concrete example of amplification, S. Clarke suggests that interested people can develop their own tools to analyse open data being released by the LHC experiments to generate excitement about the field:

> *"I love what the [LHC] experiments are doing with open data and things like this, I find that these are ways that can bring what we're doing, the concepts, to a much broader area much more quickly. [. . .] So,* ***getting others to help transmit the message is the way to go, and the only way to get them to really do that is if they're involved in the process****, if they feel they're doing something. So having other people develop their own tools to look at our data, as an example, is great. [. . . T]here's a cascade effect. . . you get others to be excited, get them to learn about it and to pass on what they've learned to their friends and their colleagues is to me the best direction to go, to have the widest impact."* (S. Clarke)

In a similar vein, K. White proposes that involving artists may provide a means to connect with those who seem intimidated by the mathematics involved in physics research:

> *"[. . . T]he standard sentence is, 'Oh, I never liked maths in school and so on, physics is school.' Whereas there are less words against art in most general form.* ***Although you could say most likely the average person out there is much better in mathematics than music.*** *<laughs> But again there is much less of a distance. And using so the art path to go back to science is probably a good approach."* (K. White)

One reason for the passive options put forward appears to be the highly specialised and specific nature of particle-physics research. R. Jackson stated that research is ultimately a job requiring years of training, thus limiting the role non-experts can undertake, a notion that P. Wood agreed with:

> *"I think they cannot really help like doing science because you need to have proper education and devote your time to it, it's a real job."* (R. Jackson)

> *"I think it is reasonable to invest part of our time in undergraduate students, tutoring undergraduate students, who might not end up in this field. But the whole notion of having complete lay people with no knowledge somehow contributing, I don't think that's reasonable."* (P. Wood)

B. Jones recounted the numerous e-mails that they and other physicists receive regularly from people who claim to have overturned physics as evidence for the inability of those without training to make a contribution:

> *"<laughs> I should send you my e-mails that I get every day. The answer to that [the question of public participation] of course is no.* ***To understand true particle physics, it requires enormous investment in understanding things.*** *From the mathematics to the background, to just the knowledge of all of the data that's taken. [...] The true lay person probably does not have the background to really make a credible contribution, no."* (B. Jones)

A. Smith was the only one who took a more nuanced approach, noting that people who have the adequate knowledge may not be in physics careers themselves, and that there should be avenues for them to contribute to research should they choose to. Following up on their statement (above) that potential contributors would need a certain level of mathematics knowledge, they continue:

> *"So yes, I think they could contribute, especially people who are not working for scientific institution or working for a university, but they are very knowledgeable, and there are such people. [...] If you go to a conference, the first thing you have to fill in the registration form is your affiliation, and not...* ***If you work for a railway company, but you know a lot about physics, then you're not allowed to go to the conference, so that I find very counter-productive."*** (A. Smith)

Specifically, the interviewee suggested that it was possible that new ideas in physics might emerge from outside the establishment, although they did admit to not having encountered such examples themselves. Further, they reiterated that such potential contributions would have to come from someone with suitable knowledge of mathematics:

> *"[... M]ost theories we use are still based on this centuries-old harmonic motion and Lagrangians and Feynman diagrams. So if we want to step aside from that, maybe even if they are not qualified, they can have some insight. I think it's very rare, but since there are many, many more people outside of science than inside, even if the proportion is tiny, then maybe they could be useful.* ***And they could be educated from some other field to have a good mathematics background. I didn't meet such people yet, but I can imagine that public engagement could help there."*** (A. Smith)

Q. Harris cited the example of a computing challenge set up by the ATLAS collaboration as a possible means of involving outside experts in the research. The challenge invited programmers to participate in a contest to produce efficient algorithms to solve specific tasks in particle-physics data analysis:

> *"How efficient it is, I don't know, but I think it's worthwhile to try these things. [...] If they can take some part of it, then I think it actually makes it more interesting to them and something that we need to be doing."* (Q. Harris)

The requirement of expertise in a domain relevant to particle physics – mathematics or programming for example – was a recurring theme. Indeed, there was an acknowledgement that particle-physics research relies on people with many kinds of expertise, from engineers and technicians to statisticians and computer scientists, as the following three quotes illustrate:

> *"The computer scientists, engineers, all of those professional categories, yes. But not... perhaps I don't see how but particle physics cannot be done without a very big array of people with different skills contributing their time and knowledge and ability. It cannot be done."* (P. Wood)

> *"Are you including things like the engineers, the laboratories, the computer scientists at laboratories, if you are talking about like that, yes absolutely? Without them we're dead.* ***You know, physicists are great generalists, they are great at asking big questions and thinking about what data means and so forth but at really technical stuff, the days for which we are good at that in the way that we need to be good at that is over.*** *[...] So our job has changed from being able to do everything to knowing what skills we need and bringing people in."* (B. Jones)

> *"[...] I'm sure that people who've not gone through and gotten their PhD or Master's degree in particle physics* can *contribute and* ***we've seen this in specific areas such as machine learning, where someone's an expert in some other area that we're using and physicists, like a lot of scientists, are not always as welcoming as they should be to the participation of other communities*** *in their world, having this false notion that only they can be the experts in it. [...] Obviously we benefit by people who are experts in electronics and other areas. And so, yeah, there is a wider community [that] can help us."* (S. Clarke)

5.2.2.2 Oversight

The importance of experts and expertise was also discussed in response to questions about societal oversight. When asked if society should be able to scrutinise and discuss large public projects before they are approved, many interviewees interpreted this matter of societal oversight as putting decision-making directly into the hands of general voters via referenda. R. Jackson expressed an outright aversion to such referenda determining which projects get funded and how, noting that these decisions may be influenced by fear caused by misinformation:

> *"I think the general public should be informed but usually, I don't know if it's hard to say but I am usually against referendum for everything because people are not well-informed. Or if only people [who were] well-informed could vote then yes but usually people are not interested and* ***so you just get votes because people are afraid because it might create a black hole or something else."***
> (R. Jackson)

They then reiterated the need to work to get widespread societal support for the research agenda but drew the line at decision-making:

> *"I think it's important that the general public supports the idea so there is not a strong block against it but I don't think we should really include [them] as part of the decision process."* (R. Jackson)

Also treating oversight as being based on society-wide referenda, H. Roberts noted that the framing of the question being put to the vote in such a hypothetical situation influences the kind of responses one might get:

> *"I mean I think a lot of these things the general public have no clue about how to approve it and if you structure it in the wrong way and ask them an open question, like 'Should we spend so much money building a machine underground in Switzerland?', they'll say no because they just have no idea what they are being asked or the implications of saying yes or no."* (H. Roberts)

They compare decision-making about scientific projects with decision-making about transport or health, emphasising the role of experts as drivers of the process with elected officials providing oversight:

> ***"Again you have to be careful 'cause politicians don't always understand the importance of long-term science whereas the scientific oversight body would.*** *You need a balance. You need some involvement of the public through their elected officials but you want to be a little careful about handing over all scientific decisions to people who do not understand, it's basically as simple as that. The same way you shouldn't have transport decisions made by people who've never worked in transport and health decisions made by people who've never worked in health.* ***You've to have a***

> ***component of the experts driving it with oversight from the politicians I think, is the truth of it."*** (H. Roberts)

As H. Roberts states above, it was generally agreed that society's involvement in research oversight should be limited to the democratic election of civic representatives. However, what is missing here is that decisions of transport and health, for example, frequently involve consultation with citizens and patient groups respectively. Others felt strongly that research funding should be governed by those with scientific training or expertise:

> *"It would be difficult probably for a general public body or something like this of many non-experts to really discuss is it worth or is it not worth what we are doing. [...] I mean to have some people as advisors, yes, that's certainly a good idea, but* ***to have say a decision by a public body which, where really no experts are in there it's probably not realistic."*** (O. Lewis)

> *"I'd rather leave the decision of which projects are financed and checking that they are brought forward correctly and the money is spent well, to policy makers by necessity and to people with at least some understanding of what's going on."* (F. Wilson)

On the other hand, it was seen as crucial that engagement activities be directed to the communities surrounding research facilities, in order to obtain social licence from them to continue running the projects as needed. C. Davies mentioned the response of the indigenous people at Mauna Kea to plans to build a telescope on land that they consider sacred:

> ***"I believe that people are important whenever you do a construction, whenever you do something that kind of impacts outside of the narrow sphere of what is already existing, they should be involved because it... it's a collective endeavour.*** *[...] In terms of how and at what level of scrutiny that's a much more difficult question but I do think it's better than to just say we're going to come in here and put this project here. It's best to have the buy-in of the local community first."* (C. Davies)

In the realm of particle physics, N. Green mentions the Future Circular Collider, a proposed accelerator that would supersede the Large Hadron Collider, as an example of infrastructure that would affect the local populace. They clearly separate the scientific decision from involving the local communities in discussions about building the infrastructure required to do the research:

> *"This is a huge tunnel, 100 km, and it has going to have an impact on the local economy in the Geneva area for sure. So I mean I am sure that it will require discussions in the communities in the Canton de Genève, Pays de Gex and whatever, but I mean* ***it's not the public that is going to decide if we want to have only a proton–proton accelerator or a proton–proton and e-plus-e-minus, this is a scientific decision, it's the tunnel they care about.*** (N. Green)

Members of society were also thought to be in a position to "steer" scientists by validating the areas of research that they pursue. The attitudes of non-experts towards particle physics, for example, can allow scientists to gauge whether society is interested in the answers to questions that motivate scientists:

> *"If we give these presentations and we try to promote our fascination to them, and if it doesn't match, if it doesn't touch them, then maybe we are wrong somewhere. Then maybe your fascination is biased to a particular kind of crazy scientist, and then maybe you have to rethink, the discipline has to rethink, '****Are we doing the right thing or are we by chance a few people with the same thoughts but which is not the overall view of society?****'"* (M. Edwards)

Similarly, G. Evans offered that interacting with those who do not work in science was valuable because it may help confront orthodox views within the community:

> *"[... I]nteracting with people that [are] not used to talk[ing] in the science jargon or to deal[ing] with the methods, for example high-school teachers as we are doing these days, it's important because they have questions or views that somehow confront your views of the field."* (G. Evans)

5.2.3 Access enhances participation

The notion of access to opportunities to take part in outreach can take on several meanings, in heavily context-dependent ways. This theme touches upon three aspects of access and how they influence outreach participation.

5.2.3.1 Access as a function of location

Access, whether to people, places or events, can be granted to a researcher by virtue of where they are located. Particle physicists may be based at universities (which place differing emphasis on teaching and research responsibilities), at national research laboratories (such as DESY in Germany or Fermilab in the USA), or at international research laboratories such as CERN. Each environment offers different

Figure 5.3: Developed thematic map for the theme "access enhances participation"

kinds of activities for scientists to participate in, including access to different kinds of resources. For example, L. Hughes notes that (differential) access to technology may influence the kinds of outreach that can be undertaken in certain settings:

> *"For example in my institute we do a lot of hands-on things in rural areas where there is very little infrastructure. So those kinds of things cannot be done, probably cannot be done for particle physics. [. . .] I think for particle physics we need a little bit of more sophistication. At least some computers to show them things."* (L. Hughes)

Unlike CERN, which has outreach activities planned throughout the year, some universities may only have certain annual events catering, for example, to the university's mission to recruit students (see § 5.2.1.3). In this case, the researchers do not have year-round access to organised outreach activities, as J. Robinson notes:

> *"While in my institute in [my country], it's a university so it's completely different. It's not something we have as a day-to-day, along-the-year activity. We have open days, with the main purpose to recruit students and then we show them the research facilities to encourage them to come and study, even if this is not something they will see any more during their studies."* (J. Robinson)

While language was not cited as a barrier to outreach participation in the survey (§ 4.2.2.5), it *can* limit access to certain kinds of outreach activities. For example, being based – long-term or as a short-term visiting scholar – in a country where you do not speak the local language well enough reduces opportunities to participate in the kinds of outreach activity you are personally interested in, as C. Davies describes:

> *"There's a language barrier here, for sure. [. . .] I did some of the open days [at CERN] in French, but it's not good enough. [. . . A]lthough I've done outreach with a very wide range of ages, I tend to like to work with kids, and there the language thing is really an issue."* (C. Davies)

Time spent in a given research environment and the expectations placed on researchers influence how much they can take advantage of opportunities to participate. For those on temporary, short-term assignments at CERN, the objective of their stay is to advance their research through meetings with fellow collaborators or participation in service work such as being on shift during periods of data collection at the collider, as L. Hughes and D. Williams explain:

> *"I participate less in outreach activities when I am in CERN. [. . .] Because of my tight academic schedule. And because I spend not too much of time in CERN."* (L. Hughes)

> *"Simply because well here, when I am here [at CERN] I am basically doing. . . I am meeting my collaborators in order to advance my research and we have this one week or one-and-a-half week time to basically get things done."* (D. Williams)

On the other hand, researchers based for long durations at institutes far from their home towns – where they may not have a big social circle – may find they have more time at hand to participate in outreach taking place outside of working hours. In this instance, participation is not so much a factor of their access to *outreach* activities but of their lack of access to *other* activities of personal interest. A. Smith suggests is the case for them:

> *"So, I have much more personal things to do in [my home town] than here [at CERN]. So I can spend a Saturday [at CERN] with visits happily. [. . .] In [my hometown], I would not do that. I would not do that on a Saturday. But that's very personal. <laughs> Because once you travel far away from home, that's a different situation."* (A. Smith)

5.2.3.2 Agency versus centralisation

Access to opportunities is influenced by two aspects that sit on opposite ends of a spectrum: agency and centralisation. Both have demonstrable value to scientists. Agency is exercised mostly in smaller teams, such as individual university departments, where all of the members have the theoretical possibility of shaping the activity in question:

> *"[A]t CERN there are so many people, nobody has ever asked me [to participate in outreach]. And also if all the activities are at CERN, it becomes a bit saturated but in [my country] you can. . . there are much less physicists at the same place. So if you do outreach activities you can really contribute."* (R. Jackson)

Agency may be a double-edged sword, with outreach being delegated to departments that might not value participation or create opportunities for its members:

> *"[My institute] leaves a lot of the outreach to the individual departments, and then the departments themselves do I think what they want to do, and certainly mine doesn't rely on the professors to do anything, so my department doesn't do much, really doesn't have its act together in that sense."* (C. Davies)

> *"It would be difficult for organising something similar in [my institute] because the scale is a bit different and we have limited amount of people who can concentrate [on outreach]."* (D. Williams)

Indeed, E. Brown remarked that individual institutions have to concern themselves with outreach for a wider number of areas (departments, fields of research) than large collaborations:

> *"[T]he institution may have many other activities going on and not only CMS. So CMS is not the highlight of that institution."* (E. Brown)

This can be contrasted by the advantages of centralised coordination of engagement activities that were identified by some of the interviewees. Sharing of material resources as well as the ability of large collaborations like CMS to hire communication experts were identified as advantageous.

> *"[A] larger collaboration has the ability to create a core group and if they centralise the funding a little bit for outreach they have the ability to hire professionals as opposed to just having physicists who like doing it. [... **W]e should centralise some of it rather than fragmenting it** because you get experts and you can actually afford to hire a couple of media experts as opposed to dividing the money over 50 institutes, where nobody can afford to hire anybody let alone an expert. I would definitely favour centralisation, or a central core team that then steers everybody else, as we have with CMS or a few other big experiments."* (H. Roberts)

Central teams can plan and execute a variety of activities into which scientists can "plug in" depending on their availabilities and interests. However, some, like H. Roberts, expressed frustration with CERN's core communication group for not reaching out to – and involving members of – the research collaborations for planning outreach activities at CERN:

> ***"I think they [the CERN communication group] have done a pretty poor job of working with the institutes, or working with the collaborations rather****. So they tend to assume that they are driving everything and they are in charge and the institutes just do random stuff, and frankly that's, apart from being very CERN-centric, I think it just misses the opportunity to do things in common more, to build bigger teams of expertise and you know... I don't think CERN ever tries to learn from the experiments or learn from other institutes because they have the arrogance of we know everything."* (H. Roberts)

B. Jones was critical of central outreach planning of CMS itself, attributing the lack of communication with CMS members interested in outreach to a fear at the top of the CMS hierarchy, stemming from a desire to control the message being communicated publicly:

> *"I think the international communication among the outreach people is poor. [... I]t has to do with the fact that **the people at the top of the experiment are deathly afraid of the media and they don't... they want to keep control of the message** and it's not that they are good at outreach, I mean the spokesman of the experiments, they might be OK as an interview but it's not their main interest. But they are just afraid of what will be said and then they figure they'll have to clean up the mess."* (B. Jones)

They also express resentment at what can be perceived as an inner circle of communication professionals who are reluctant to work with scientists who are keen to shape the outreach activities in question:

> *"[... T]he people they trust are communication professionals, which is why it goes up to [the head of CERN's communication group] and then it fires out to the other national-lab comparable people. [...]* ***I don't think they utilise their scientific talent worth a damn because of this very hierarchical thing and their trust of communication professionals."*** (B. Jones)

I therefore argue – as H. Roberts also does above – that ideal conditions would involve an admixture of both aspects, with scientists co-creating activities with the central communication professionals. This also lowers the barrier of entry for scientists who are keen on participating in outreach but who may not know where to start: the central team can facilitate their participation. Federated hub-and-spoke structures coordinating outreach in large collaborations to provide access to outreach opportunities to a greater number of scientists can also be supported directly by research funders, without making outreach participation a requirement for grants (see below).

5.2.3.3 Making participation non-mandatory

A third dimension of access concerns access to training and skills development. This was raised in the context of the value of including outreach plans in grant applications and in discussing the ability of scientists to communicate particle physics. Some expressed reservations about making funding contingent on outreach participation. Reasons included differing abilities and skills among people in general, with concerns that participation of those with limited communications skills or a lack of interest being detrimental to the activities.

> *"We are* not *good at [communication], and I have to say that it took me many years before I could come up with coherent speeches or conversation pieces, storylines to convey what we're doing to the public. It takes a lot of work to do that and most of the people in our field don't go through that effort."* (S. Clarke)

H. Roberts was unambiguous in stating that outreach participation should not be tied to grants:

> *"I don't think it should be a requirement, no. I really don't. I think major programmes such as the LHC needs to have an outreach component but to make it a component of every single grant I think is not the right granularity.* (H. Roberts)

Asked to elaborate, they contrasted the size of grants that small groups receive with those that bigger ones do, raising their earlier point about central teams being able to hire professionals courtesy of larger budgets:

> *"Well, you are given a specific grant and it could be for a few hundred thousand dollars, you know, for a small group, up to a million dollars for a big group, and to actually insist that every single group has some of that, you know, engaged in outreach is a very fragmented way of doing it. [...] And* ***I think it's natural some groups are very good at doing outreach and others aren't, they are better at doing something else****. So I don't think it particularly has to be every single person involved in outreach. The same as you don't have every single person involved in writing papers or training students or whatever, it depends."* (H. Roberts)

C. Davies recounted grants being awarded to faculty members who were not themselves involved with outreach, with the students who wanted to participate in outreach not having a straightforward mechanism to get funded to do so:

> *"I just remember as a student when I worked in groups that had a lot of strong outreach components, we had trouble getting funding and we knew there was all these faculty that were writing these grants that had outreach components they weren't doing anything about, and we were like, just give us the money, we know what to do with it."* (C. Davies)

B. Jones was also sceptical about whether making details about one's outreach participation part of the grant application carried value, as it might depend on arbitrary criteria chosen by individual evaluators:

> *"The person reading the grant will make a decision of yes or no. If they value outreach, yes. [... I]t can be pretty pro forma, I mean it's a box to check off. [...] Yes you have to for certain grants but more often than not it doesn't, usually doesn't make the decision any different."* (B. Jones)

A better strategy to making outreach compulsory to increase the number of scientists participating in it would be to make training widely and freely available to those who are interested. The interviewees acknowledged the value of the communication trainings they themselves had received:

> *"[P]eople would really benefit from media training. To learn how reporters are thinking, how the public are thinking, to cook it down, do not use this LEP slang, and people will not understand this."* (I. Wright)

> *"Those people who participate more in outreach have typically received some kind of training in outreach, or in science communication in general, both written and media-like."* (M. Edwards)

Rather than reducing outreach participation to a perfunctory, box-ticking exercise, it is of greater value to give scientists access to appropriate training and reach out within the community to ensure that those with interest – especially junior members – are equipped with the skills they seek.

For example, researchers employed by CERN do not have funding agencies to report to directly, and so do not have any specific outreach requirements. However, the laboratory invites all newcomers to volunteer for activities such as on-site visits and offers them training to do so.

> *"[I]t's true that when I was at CERN as a Fellow, we are asked to be guides, at least at the time we were asked to be CERN guides and I specialised on CMS and I think this was also important to reinforce that aspect. So it was not part of the application but then I was asked to do it when I arrived at CERN. . . "* (J. Robinson)

> *"There was something which was very nice at CERN at some point, was that when you became a guide [. . .] there was a training course on communication, formal course on communication, and you were recorded when you gave your presentation and then you would sit down with someone dissecting what was going on."* (P. Wood)

In addition to the the advantage that large collaborations have in comparison with individual research departments to pool resources together to dedicate to outreach (§ 5.2.3.2), the particle-physics community in particular has a small set of topics to cover as a whole:

> *"The difference here, well, CMS as a collaboration, and also CERN, we have one general topic that distinguishes it from a big institution like a university where their science is multi-faceted, you there can talk about many topics. Here we are basically one main direction with sometimes some side bars."* (K. White)

This means that a small number of scientists who are active in outreach can nevertheless represent the entire collaboration's research:

> *"[. . . Y]eah it's different because in a small group you have more activities per person to do, as a work, as a research activity and there is less time for outreach. [. . .] And there is a difference because* ***the more people you have, it is more likely to have someone who has time for dedicating time to [outreach]****, in the small groups it's more difficult."* (G. Evans)

Indeed, scientists based at any of the many universities and institutions around the world that are part of the CMS collaboration can engage in outreach concerning CMS, the LHC or particle physics more generally. And the collaboration's activities based at CERN in particular can rely on many different individuals to participate on different occasions. Scientists working in the large particle-physics collaboration like those at CERN may therefore share more equitably the responsibility for representing their field in public-engagement activities.

5.2.4 Communicating improves communication

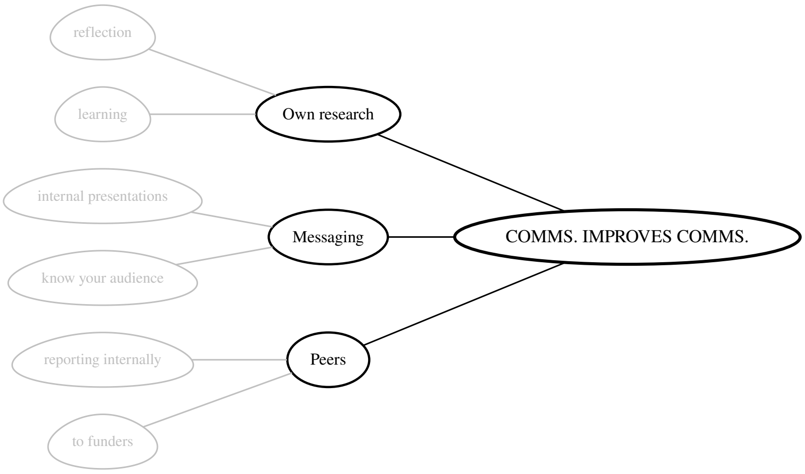

Figure 5.4: Developed thematic map for the theme "communicating improves communication"

> *"If you try to communicate you improve your communication skills in general [. . .]."* (N. Green)

Evidence for this tautological, seemingly self-evident theme can be found in responses to two questions concerning communication. The first was about formal communication to funding agencies, in response to requirements to include outreach plans in grant applications. The second was about whether outreach participation had changed the way the interviewees communicate with their peers.

5.2.4.1 Understanding one's research

Collectively, scientists on CMS report to over 40 funding agencies globally and therefore do not have identical, or indeed uniform, requirements concerning the inclusion of outreach plans in grant applications. Some like S. Clarke noted that some of their funding explicitly excluded outreach activities:

> *"Um, well, actually it's often not included specifically, because some funding providers don't want that, you know. And that's a shame. They don't wanna include in research funding outreach funding.*

> *[…] Other things we're doing in research, even including software efforts was hard to put in there, let alone outreach."* (S. Clarke)

For some, outreach is couched in the framework of service to society, and is not something researchers are asked to articulate when they first apply for funding, though it may become relevant to other aspects of their careers:

> *"[W]hen I applied [for my current position] I was never asked about something else than my research. And I got the position. Now when I asked for promotions […]* ***I have to report about not only my research but also my involvement in teaching and service to the society****. And that service includes outreach plus role as expert in committees plus service to the institution and so on. [… T]he funding agency just care about research, a bit about services but it's really 95% about research."* (J. Robinson)

Nevertheless, among those who reported including details about their outreach plans, there was near-universal positive sentiment, with R. Jackson and C. Davies noting that the inclusion of outreach plans was as an opportunity to demonstrate one's interest and ability to communicate physics more generally:

> *"You need to communicate your work also to other physicists and if you do outreach it means you can also 'sell' your work to others and present in a good way. Or at least that you had some interest in communicating correctly and I think that's important even just for physics not for outreach. But it shows that you can do it also in physics."* (R. Jackson)

> *"I think it's an important skill of a researcher to be able to* ***demonstrate the value of your work to outside people****. […] It used to mean that I did outreach and I did research and I usually talked about my outreach and my research. But now to make it a nice package and I think also to maximise efficiency in terms of my time, certainly something that I focused on in my last grant application was making them all connected in a way that I hadn't in the past."* (C. Davies)

J. Robinson remarked that the exercise enabled them to reflect on their research in ways that are beneficial to the research itself:

> *"[… T]he fact that you have to think about the outreach, how the research you propose can be communicated to the public, helps to a bit step back with respect to the project and check the overall*

> *consistency and to go a bit beyond the hardcore science that you put in it. [...] So in that sense, in the process of preparing the application, the outreach part may be good for also the scientific part."* (J. Robinson)

Moving away from grant applications, it has been suggested that public engagement itself can enable scientists to think about their research in new ways, and both E. Brown and A. Smith offered that this is possible for them. E. Brown suggested that the act of explaining their research to someone unfamiliar with it might lead them to new ideas, while A. Smith remarked that questions they were asked during outreach events led them to look up something they were themselves unfamiliar with:

> *"[S]ometimes when you are speaking to people you get ideas, it really happens to everyone I think, it's not only for me. When I am explaining things first of all I understand them better. And then when I understand them better I could have a new idea."* (E. Brown)

> *"And they can ask extremely good questions, so that also helps. I'm learning a lot from them as well, not because they tell me something, but because they ask me something which I have no idea and I have to look up.* ***So I have looked up many things already which I didn't ask myself about but they did****. So that was also good. I can recommend outreach to some people who think they are too... they are very informed, they will notice that they are not informed enough. <laughs>"* (A. Smith)

5.2.4.2 Peer communication

Most of the interviewees, when asked to reflect on whether outreach participation had changed how they communicate with their peers, touched upon on or both of two aspects: identifying a message and knowing one's audience. Being part of a large collaboration like CMS involves attending regular meetings and often presenting one's work at meetings attended by hundreds, with frequent discussions with colleagues in the room and connecting via video-conference calls.

Concerning the first aspect, S. Clarke spoke of how preparing presentations aimed at the non-expert public had helped them realise the importance of identifying a clear message to be conveyed in the talks:

> *"I give much better talks now, I think, to my peers. [...] I've learnt to be more engaging, to start out with something, maybe start out with a story, say something that will grab my colleagues' attention, and then* ***I learned most importantly how to focus on the one thing that I want to get across***

> ***to them.*** *[... E]ven talks with my colleagues, I've learned that I should get that point across, that single message, I should make sure they got it, check with them they got it, and don't be afraid to repeat the message at the end..."* (S. Clarke)

A. Smith noted their own aversion to communicating with their peers anything that they do not understand well themselves, and observed that participation in outreach allowed them to practice this attitude with non-specialists resulting. They claimed that this improved their communication with their colleagues:

> *"Peers meaning other physicists? Probably it did. <laughs> [...] I got very, very positive feedback from groups I was coordinating in CMS, about clarity and simplicity, that I did, I communicated with.* ***So I never try to confuse people. And I think it's a good way to exercise that attitude with visitors and outreach, because there you really have to think about how to not confuse them or not to lose their attention."*** (A. Smith)

O. Lewis similarly observed that outreach had changed their way of thinking about communication with their peers, exemplified by the statement that they had learnt to provide an overview instead of taking an immediate dive into the depths of the scientific details:

> *"I think because I'm used to explaining things for non-experts, I also try to communicate with my colleagues maybe in a slightly different way, not so much in detail but in general more understanding, more... in a different way, exactly. So, you always can go in the details, with formulas and whatever and drawings, but* ***you first should give what is the point, what is the matter and not going immediately deeply into the matter and then you're lost in details*** *[...]. So I would say it has changed, yeah, the way of thinking, at least in my way."* (O. Lewis)

The second aspect drew parallels between the diversity of people attending an outreach event and the diversity of expertises and experiences concerning the research topic within the collaborations. Assuming everyone present was equally familiar with every topic of discussion was identified as problematic. C. Davies noted that identifying the level of knowledge on a given topic, among attendees of internal meetings, was something they had learnt from outreach participation:

> *"I think that I think a lot about how to explain things with a minimal amount of jargon if I can, to my colleagues.* ***I think working a lot with outreach helps me gauge a little bit better the level of understanding of an audience, no matter what the audience is,*** *if it's an outreach*

> *audience or a physics audience. And also just the value of speaking not to the expert in the room, especially because when you do a lot of public outreach there's a lot of times you'll have people there who've read every single popular-science book ever and I don't really care about talking to them,* ***I care more about talking to the people who have a passing interest****. So that kind of similar thing translated into your group meetings, or your analysis meeting. [...] And I think it really did impact, honestly, how I work."* (C. Davies)

N. Green emphasised that even peers may have different degrees of familiarity with a particular research operation, and that one should not be too technical when providing explanations:

> *"[...] I mean you have to make the effort to explain things and this means that you realise that you should not be too technical when you discuss things. And this is something general, because also* ***when you describe to a colleague something you should remember maybe they maybe have not done that particular series of operation so you should not assume that he knows everything."*** (N. Green)

Being aware that one's own work may be of a specific technical nature but that what an audience of peers may be interested in is the more general take-away message was key to ensuring that the majority could participate in the ensuing discussions according to J. Robinson:

> *" I think that in the end at a different level you have the same kind of issues [in both outreach and communicating with peers]. You always do something that is more technical and also when you go to specialised meetings, approval meetings, what you have to do is communicate about the special things you did without going too much into the technical details. Because* ***either people know already about the technical details and they don't care or they don't know and they will not be about to grasp that in a ten-minute presentation****. So to find proper equilibrium to pass the key message and be ready to answer more precisely the question comes, but still pass the key message."* (J. Robinson)

A. Smith referenced the diversity of experience within the peer community, remarking that it was important to make sure the younger students present did not feel alienated by the discussions at meetings:

> *"So I think we have to be careful with peer communication, just to not also falling on the other side of the horse, not trying to bore the big characters in the audience, but also* ***to care about – that is***

> ***also an audience – to care about the students a bit, who are not yet familiar with things.”*** (A. Smith)

On the other hand, K. White speculated about the direction of influence, asking whether the mind-set of explaining their research clearly to different audiences did not emerge first and affect both peer communication and outreach:

> *“I wonder if one could not turn the question around. [. . .] I have the tendency to make a huge effort to explain things in a way that people can follow. That probably is true for any kind of talk I am giving, if it’s a very scientific talk or it’s an outreach talk. What I don’t know now is which direction has influenced which other, exactly to me. Yeah, it’s a mind-set. Maybe it comes first and then it effects both directions.”* (K. White)

5.2.5 Particle physics is not relevant to people’s lives

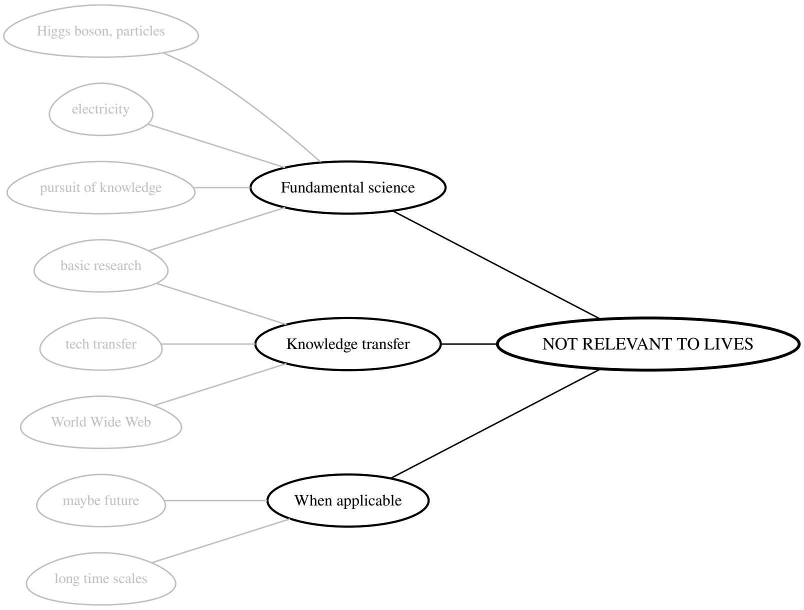

Figure 5.5: Developed thematic map for the theme “particle physics is not relevant to people’s lives”

As a fundamental science studying the make-up of the universe, particle physics does not deal with everyday human life, as E. Brown explains:

> *“So what are we doing are CERN? We are looking for the fundamental forces and the fundamental particles and how they interact with each other and then to relate that to how the universe was born. Now how does a lay person who is working in a [grocery shop in my country] bother?* ***If you have found the Higgs boson, so what?***” (E. Brown)

The interviewees for this project were asked if particle physics was relevant to everyday lives. The responses, independent of their flavour, concern two orthogonal properties of relevance: directness and immediacy. The consensus was that particle physics is neither directly nor immediately relevant to human life.

5.2.5.1 Directness of relevance

For many, such as F. Wilson, particle physics was not in any way directly relevant to our lives and they also remarked there are no guarantees it would affect our lives in a direct way in the long run:

> *"I mean there's not much if anything in what we do and in what we study that affects our day-to-day lives. It's really a matter of understanding nature, it's not… I don't think anybody claims that what we do will have a direct impact on people's lives in the next, I don't know, ever."* (F. Wilson)

Perhaps more fatalistically but most directly, for N. Green, the relevance of pursuing basic research was in its ability to elevate humanity as a whole, in order to prevent war (see also § 5.2.6 below). The view mirrors narratives of science as pure, unbridled progress.

> *"So it helps answering some of the basic questions, progressing in understanding the basic questions. […] The main reason is [to] progress the understanding and I think mankind needs progress in the understanding. [… R]esearching about the progress, it is the only alternative we have with respect to war in a way."* (N. Green)

Some, like H. Roberts, contrasted particle physics with other domains of science, noting that it has far less relevance than other areas of research even within the natural sciences:

> *"No, I don't think it is particularly as a discipline. […] So I think when people say why is it relevant, they're normally saying why should we fund it. […]* ***I don't think one should oversell the fact that it is relevant 'cause I don't think it is particularly relevant in a lot of ways compared to other science at least.*** *There's a lot of other sciences that are very, very directly relevant on a day-to-day basis like energy research and things like that."* (H. Roberts)

Where direct connections to our lives *do* exist, they do so through technology. This technology could be the result of applying the knowledge generated from particle physics or it could be based on technology that was specially developed to do the research:

> *"[. . . I]n a trivial way because of the applications first, because there are as you know* ***many medical applications of accelerators****. And they have to know that many things they consider utilities or things they are used to, like [. . .] the treatment in medicine with particle beams etc., this originated in the fundamental research."* (G. Evans)

A. Smith added that the influence of particle physics is all around us even if non-scientists are not always attentive to its presence:

> *"They don't always notice that, but they use and they encounter a lot of the technologies that we are using at CERN starting from vacuum technology to hadron therapy to safety applications to satellite-image processing, and MRI in the hospital and CT and positron emission tomography [PET]. So they do encounter particle physics a lot. Even if they don't immediately notice."* (A. Smith)

The role that fundamental physics has played in influencing technology in the modern world was also a common refrain. E. Brown and M. Edwards remarked that these technologies were not developed because particle physicists set out to do so; the applications and spin-offs are an indirect consequence of the pursuit of knowledge:

> *"[. . . Y]ou go back to how relativity has helped us into satellites in space, in imaging and all that and then you say that the mobile phone that this [grocery-store worker] is using is actually using the technology that has come out because of the quest for the understanding of the universe."* (E. Brown)

> *"But it's not why we do science. These are the two aspects we should differentiate.* ***There is one that is purely fundamental and that is more philosophical and yes by understanding the nature we may feel differently in our everyday life****. And then by doing the research we do, we produce some technological material that can then impact people in their lives as well. I think both are important."* (J. Robinson)

Others, such as H. Roberts and P. Wood, also noted that the applications did not emerge from the research in a pre-conceived manner but went even further to add that the development was often done by people who were not necessarily particle physicists themselves.

> *"I think if you want to make direct links one can talk about how particles are used in various ways like X-rays or radioactivity in medicine or things like this but its again not. . . you don't particularly need particle physics to do most of that, it's more applied physics or whatever."* (H. Roberts)

> *"Now did particle physicists invent quantum mechanics and went about doing all of the inventions? No, but it's particle physics that somehow puts this in evidence. [...] It's physicists like those that make up stuff like quantum mechanics, the theorists. The experimentalists do experiments that show that the thing works and of course* ***there is a whole body of people who bring it to the innovations and inventions that now we all cherish*** *[...]."* (P. Wood)

At the same time, P. Wood was keen to stress that the applications should help society appreciate the material value of the fundamental sciences even if they are not directly relevant:

> *"These things percolate and I think if people would know more about how things came about they might appreciate better why such apparently useless things should be done."* (P. Wood)

The most tenuous connection drawn in terms of the relevance of particle physics was to the creation of the World Wide Web by Tim Berners-Lee while at CERN, a development in computation and information technology that happened to have taken place at a particle-physics laboratory. These was mentioned by most of the interviewees in some way or another, exemplified by the following quotes by N. Green, J. Robinson and P. Wood:

> *"[...] And the fact that* ***we developed the World Wide Web because we wanted to communicate between scientists****. So there are also things that are not really related really, maybe not the purpose of research, but they give return and economical return which is larger than the investments already."* (N. Green)

> *"Of course then you have applications and the fact that [the World Wide Web] was discovered, well was not discovered, but invented at CERN, shows that what we do can have a direct impact on their lives."* (J. Robinson)

> *"Just the idea that you click on a link and go to a related site was born of the need to organise all of the new information that physicists were trying to put together at LEP [Large Electron–Positron collider] times."* (P. Wood)

While it can be argued that a unique set of circumstances led to Tim Berners-Lee developing the web at CERN, and CERN *did* play a role in releasing it freely and openly for anyone to use, it is still somewhat of a stretch for particle physics to take credit for it. Overall, though, the near-universal perception was that particle physics had no direct relevance to human life, even if we are able to enjoy the technological fruits of the knowledge it generated.

5.2.5.2 Immediacy of relevance

The second axis concerns the immediacy of relevance and continues the relevance-through-application argument. O. Lewis asserted that if research into the fundamental laws of the universe were able provide technological solutions to humanity, it would do so on generational time-scales:

> *"[… A]s we do fundamental research, it's not at the very moment our discoveries don't have an immediate impact to their day-to-day life, that's clear. But we have to think in generations, I would say. So it's not for us, in fundamental research, as I said, there is not the immediate product development of a device or god knows what based on our discoveries now, and so we have to think in longer timescales, I would say. […]* ***It's relevant in the future, yes.*** *It's an investment in the future."*
> (O. Lewis)

O. Lewis and P. Wood both posited that particle physics was certainly relevant on such long time-scales, citing various technological breakthroughs that physics had led to in the 150 years:

> *"[N]ot particle physics, because it's too young so to say, but say electromagnetic waves, yeah, described in the mid of the nineteenth century and so on and the result we have radios, TV, transmitters, all these technology, wireless technologies, something like that. All are quantum mechanics, and even general relativity. Our GPS systems do not work reliable enough without general relativity, corrections due to general relativity. I try to give these examples, that* ***there is not an impact of our results to their day-to-day life now but there could be an impact in 50 years.****"* (O. Lewis)

> *"Well ever since some guy put his wife's hand under an X-ray machine, an X-ray beam, and showed in a photographic plate that you could see the ring and the bones but not the flesh, that we've been creating different ways of looking inside the human body, allowing us to diagnose earlier, faster, better. [… I]f there is no immediate impact it becomes hard to value and so fortunately* ***with particle physics we have a long tradition of these since the discovery of the electron that you know playing with these things ends up giving some revolutions.*** *Quantum mechanics has completely changed the world as we know it."* (PT-M-ext)

Of course, the question of *what* such practical outcomes could be in the distant future remains speculation. Indeed, C. Davies seemed more hopeful than certain, stating that their own limited imagination prevented them from guessing about potential future uses of the outcomes of particle physics:

> *"Clearly, I don't think anything we learn about the properties of the Higgs boson is going to impact the average person's daily life, but I think the endeavour of particle physics, and from that, the general knowledge, which you won't know the impact of it, there's the technology spin-off, there's the knowledge that… you know,* ***we have very limited creativity, so there's no way I can say how the stuff will be used, but in a hundred years who knows?*** *There's all that, which I do actually believe."*
> (C. Davies)

Though the history of physics in particular is rich with examples of technologies that emerged as a a result of scientists simply experimenting out of curiosity to understand the laws of the universe, fundamental research offers no guarantees of developing useful applications of any kind. It is clear that on the immediacy axis as well, particle physics appears to have only remote relevance. However, as we are frequently reminded by the stock market, past performance does not guarantee future returns. The suggestions of long-term relevance may well be a means to guarantee short-term societal support for pursuing research.

5.2.6 Science is culture

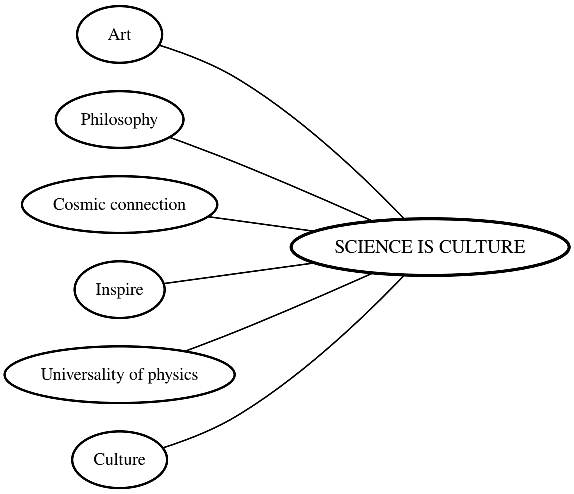

Figure 5.6: Developed thematic map for the theme "science is culture"

The final theme identified coincidentally connects the Merriam-Webster dictionary's words of the year for 2013 (*science*[*]) and 2014 (*culture*[†]). It pertains, once again, to the fundamental nature of particle-physics research, and draws an equivalence between advancing knowledge about the universe and making contributions to human culture. Here, the choice of "science" is not innocent: "science" and "research" are sometimes used interchangeably in English, although the latter is more inclusive to

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[*] https://www.merriam-webster.com/words-at-play/words-of-the-year-decade-in-review/2013-word-of-the-year-science

[†] https://www.merriam-webster.com/words-at-play/words-of-the-year-decade-in-review/2014-word-of-the-year-culture

both the social/human sciences and to the arts and humanities. However, in this instance, the theme concerns itself with the research in the so-called “natural sciences”, which are not typically seen as belonging to the cultural sphere.

Interviewees remarked that their pursuits in the laboratory constituted a cultural endeavour. In the same vein as the theme on relevance (§ 5.2.5), interviewees were keen to note that frontier research in the fundamental sciences is not performed to address specific practical or societal problems but for what they considered to be higher ideals:

> *“I mean people don’t care about quarks and gluons and Higgs field and things like that, not in the slightest. What I think it does is it sort of… **it’s important for the nobility of the human spirit** to understand that we small blobs of protoplasm can actually understand the universe.”* (B. Jones)

Similarly, R. Jackson drew parallels to art. In this regard, they addressed the question of the *necessity* of pursuing fundamental physics. When asked whether particle physics is relevant to our lives, they said:

> *“Yes and no. Not everyday life but just, it’s something… it belongs to humanity in general. **I mean it’s something that makes us richer, I mean the society in general but I don’t think it impacts everyday life.** I think also people could live without particle physics but it’s a bit like art. We can live without but **we are a better society if we live with.**”* (R. Jackson)

K. White also saw research as belonging in the same category of cultural activities as music, painting and literature. The act of creating knowledge, to them, was a fundamentally cultural one and a fundamentally human one at that:

> *“I call myself, I don’t know what is the right word in English, in [my language] there is a clear expression, a cultural activist, a cultural person, I am a cultural… **I am somebody doing culture.** […] [P]eople should realise that asking questions about nature and so on, so doing science, is a fundamental part of human culture. It’s as fundamental, and the activity in the end is very similar to kind of any artistic activity or whatever kind of activity which you would call cultural activity. But typically we have gone in the direction that if you talk about cultural activity, people think about a musician or a painter or a writer, but I am convinced we are doing a cultural activity because creating knowledge – that is the word I was looking for – **creating knowledge is really one the fundamental pillars of human culture, which distinguishes us** [from other animals]. And I think science should not be shy of saying this.”* (K. White)

G. Evans espoused identical views. To them, communicating about particle physics was a way of making a cultural contribution:

> *"Yeah, [the] main purpose is to as I said to contribute to culture. Culture typically is associated to art and music but I think, **I am convinced that the knowledge is also culture and culture is not complete without knowledge**. Particle physics being a fundamental part of science is one of those very important parts that have to be introduced in the culture of society."* (G. Evans)

J. Robinson and M. Edwards referenced philosophy, taking one back to the origins of fundamental physics as "natural philosophy". J. Robinson said that :

> *"I think it's important for people to realise that we have questions that are purely fundamentals and they should feel concerned about that. It can be particle physics, it can be something else. It's as important... It's like philosophy! **How does philosophy impact people's lives?** I think it does in the way that you behave and you grasp the nature and the world around us."* (J. Robinson)

In response to the question about the relevance of particle physics to our lives, M. Edwards said:

> *"In some sense yes, but then you touch philosophy in some sense. [...] In some sense to demonstrate to people that even a scientist, an exact scientist, who for many people is there to help them [with] their health, the world around them, their well-being, **that also scientists explore things, like exactly they do if they enter the book store**. [...] So, **that's philosophy here**, but I think that's a key part which society has to learn not only from particle physics but from all science. **That's much more important than to understand what dark matter is.**"* (M. Edwards)

The comparison seems to be popular within the community. Unprompted, P. Wood made a reference to art, but in the sense that they perfectly understood why people might not be convinced by this line of reasoning. After all, P. Wood admits, they are themselves sometimes unconvinced by art:

> *"I don't really believe in the artistic pursuit of knowledge and making man more illuminated being sort of thing. [...] I find that it's not something that would convince me. [...] So I prefer these more quantitative ways of measuring the impact. Because it's things that change your life. I mean the whole notion that, 'Oh, now we understand the universe better...' Perhaps I have had too many visitors who just say or frown 'So what?' [...] I mean when I go to art gallery the question 'So what?' comes to my mind many times."* (P. Wood)

P. Wood has a point. While the comparisons to art and philosophy do have their merit, we should be wary of using them to *justify* building large and expensive machines. Philosophy is certainly a less costly enterprise for society to support. However, the idea that science is culture certainly appears to be deeply ingrained in the consciousness of the particle-physics community, as this theme shows.

5.3 Summary

A qualitative analysis was performed using 19 personal interviews conducted with scientists from the CMS and ATLAS collaborations. The themes identified from the analysis show a rich variety of views regarding outreach. In particular, the scientists generally saw public engagement as dissemination or education, done in response to the financial support from society, and only occasionally did they refer to two-way conversation between themselves and society. The participatory paradigm of PEST was resoundingly rejected for reasons ranging from the impracticality of non-experts without training in mathematics making a direct contribution to research and wariness to letting non-experts have influence over the long-term funding of the research field. The scientists, most of whom have outreach experience, were keen to be involved in outreach, with some attributing their participation to the communications training they received. Many felt it was better for funders to directly support outreach by establishing the infrastructure necessary for scientists to participate in activities, without requiring their participation to be tied to their grant applications. However, the act of including outreach plans in grant applications was fruitful to the scientists in terms of being able to articulate their research, and they also reported improved communications with their peers as a result of participating in outreach. Finally, particle physics was not seen as being directly or immediately relevant to everyday human life, although the pursuit of research was framed as a cultural activity.

Chapter 6

Discussion

Public engagement with science and technology can take on different forms, in different scientific contexts. In this regard, the international community of high-energy particle physics is a unique context. In this community, scientists from across different linguistic groups use the term "outreach" in English as a synonym for public engagement (see § 2.6). Therefore, for the purposes of this doctoral research project, outreach and public engagement have been used synonymously and interchangeably to refer to "activities designed for an audience outside academia" (Crettaz von Roten, 2011, p.54).

In this thesis, I present the findings of a study into the community of researchers working in high-energy particle physics, represented by the CMS collaboration at CERN. The following four research questions are addressed here:

1. **RQ1**: "What are the attitudes towards outreach within the particle-physics community, including the motivations for – and barriers against – participating in outreach activities?"
2. **RQ2**: "Do these attitudes towards outreach within the particle-physics community vary with respect to age, gender and outreach experience?"
3. **RQ3**: "How, if at all, are these attitudes influenced by (a) differing expectations from funding bodies and (b) being part of large, international collaborations?"
4. **RQ4**: "Are participatory paradigms present in the discourse concerning outreach within the particle-physics community, and what is the perceived relevance of the research to the everyday lives of non-specialists?"

6.1 Attitudes, motivations and barriers

Bohner and Dickel (2011, p.392) define an attitude as “an evaluation of an object of thought” and as something that can be applied to “things, people, groups and ideas”. This allows us to examine the attitudes towards public engagement within the particle-physics community through several different attitude objects, such as their views on the public’s interest in science, their preferred groups to communicate their research to, any benefits that they perceive to derive from outreach participation. The survey data show that the **attitudes** within the CMS collaboration towards public engagement are generally positive (§ 4.2), in line with previous research in other fields (e.g. Poliakoff and Webb, 2007). However, this must be viewed in light of the high proportion of respondents who report having outreach experience: most claimed to have participated in outreach activities at least once in the previous year (n=329, 84% of total). While this is higher than the proportions recorded in previous surveys done in the UK of scientists from different fields – 74% in Royal Society, Research Councils UK and Wellcome Trust (2006, p.10) and 78% in Hamlyn *et al.* (2015, p.19) – it is not particularly remarkable in itself. As the qualitative analysis showed (§ 5.2.3.2 and § 5.2.3.3), the barrier of entry for outreach participation is low in the tight-knit particle-physics community as a consequence of a large number of centrally coordinated events.

The positive attitudes identified from the analysis of the survey data are underpinned by moral norms. That is, the **motivations** for participation are the perception that outreach participation is a duty and something to be done in return for taxpayers supporting research. These two aspects were also highlighted by the interviewees when asked to define public engagement. In addition to its moral nature, conceptualising outreach as something done in *exchange* for taxes also shows its transactional quality as a legitimising exercise, as evidenced in the interviews (§ 5.2.1.2). At the same time, few agreed with the notion that outreach is part of wider academic culture or that it is done to fulfil societal expectations concerning public engagement. It is worth dwelling on this. It is curious that outreach is not considered to be embedded in the cultural milieu despite the high number of respondents with outreach experience, and of those who report receiving support for outreach participation from both their colleagues and from their institutions (see below in this section). In conjunction with the enjoyment and job satisfaction from outreach participation reported in the survey (see below in this section) and treatment of scientific practice as a cultural one in the interviews (§ 5.2.6), outreach can be seen as being motivated by a desire to share not only their research but also their own excitement regarding their research.

With regards to the benefits of outreach participation, the MORI (2000) study asked respondents to list what benefits they gained and the responses were later classified. In this doctoral research, those categorised responses were presented as Likert-type items to be rated on a five-point scale of disagreement/agreement. The strongest perceived benefits concern external benefits: to society more generally, including to funding agencies. This once again brings to light the legitimising purpose of outreach, to "guide" society to make informed decisions about future funding of research. However, the weighting of societal benefits also agrees with the framing of outreach in the paradigm of scientific literacy, serving the purpose of advancing the public understanding of science (see § 6.4 below). Similar benefits were also identified among scientists engaging via theatre (Dowell and Weitkamp, 2012), in environmental sciences (Riesch, Potter and Davies, 2017) and through outreach targeting education (Andrews *et al.*, 2005). Researchers in Madrid have found that "[t]he most important motivations have to do with the desire to increase the public's interest in and enthusiasm for science, the public's scientific culture, and public awareness and appreciation of science and scientists" (Martín-Sempere, Garzón-García and Rey-Rocha, 2008, p.349).

In terms of benefits to oneself, personal outcomes such as enjoyment and job satisfaction were valued most highly, while among professional benefits, scientists valued the communications experience they gained from outreach and thought themselves better scientists for taking part. Andrews *et al.* (2005, p.281) note that some groups of scientists from a USA-based university were motivated by "the chance to improve their teaching and communication skills". Over half the survey respondents disagreed with the idea that scientists lack communication skills. However, several interviewees reflected on their own improved communication skills § 5.2.4, which they attributed to having to communicate with groups who might not be intimately familiar with their research domain. So, although the scientists do not believe a of communication skills would act as a barrier for outreach participation, they nevertheless acknowledge the that taking part in such activities improves their ability to communicate their work.

Research into the impact of outreach participation has been mixed. Some, like Ecklund, James and Lincoln (2012), have reported scientists viewing their involvement in outreach as detrimental to their careers, while research done by Royal Society, Research Councils UK and Wellcome Trust (2006) portrayed it in more neutral light. In the results reported in this thesis, outreach was not seen as particularly valuable for career advancement, in line with work done by Poliakoff and Webb (2007, p.255), which found that "some [scientists] intended to participate despite [recognising] few potential career benefits", fitting "with the notion of the 'civic scientist' who chooses to contribute to wider society for personal rather than professional reasons". CMS scientists also did not believe that outreach participation helps them think about their own research in new ways or that it opens up collaboration opportunities.

The so-called "Sagan effect" is frequently listed among the **barriers** to greater participation in public engagement. This effect is named after the astronomer and science communicator Carl Sagan, and is the belief that outreach participation is for scientists "who are not good enough for an academic career" (Royal Society, Research Councils UK and Wellcome Trust, 2006), despite evidence to the contrary (Jensen *et al.*, 2008). CMS scientists did not report experiencing the Sagan effect, and by and large reported being supported both by their colleagues and by their institutions. However, as stated above, they did not go so far as to claim outreach participation is part of the research culture in their home countries.

Environmental constraints were not cited as key barriers, unlike the Royal Society survey in which 64% cited a need to spend time on research as a barrier (Royal Society, Research Councils UK and Wellcome Trust, 2006). However, as one of the interviewees noted, being based at a research centre far from their home town left them with a lot of spare time on weekends to participate in outreach, something they would not do if they were in their home town with family and friends (§ 5.2.3.1). Despite noting that the language in which an outreach activity is conducted was not a barrier, most survey respondents nevertheless participated in activities held primarily in their native tongues. A possible explanation, although this was not explored in this research project, may be that those who may not speak English as a first language (a considerable proportion of the CMS collaboration and of the survey respondents) may nevertheless be comfortable participating in outreach activities in English, given that this is the collaboration-wide lingua franca among researchers at CERN and elsewhere. At least one English-speaking interviewee noted that participating in activities in French proved challenging and limiting (§ 5.2.3.1). Being part of a big collaboration lowered the barrier of entry for outreach participation (§ 5.2.3.2 and § 5.2.3.3); sharing the responsibilities for representing the field of particle physics meant that they were able to distribute outreach activities among a greater number of people.

Barriers associated with perceived behavioural control and perceived suitability of research (Poliakoff and Webb, 2007) were absent. That is, in the case of the former (control), the scientists reported high levels of confidence that they can both address the questions posed to them during outreach events and prepare the materials necessary for the activities in question. In the case of the latter (suitability), a majority were of the opinion that their research is *not* too complex for outreach participation. This is particularly important to consider in light of the theme drawing equivalence between science and culture (§ 5.2.6), as particle physics is not seen as something inherently beyond the ability of people to grasp without extensive formal training.

6.2 Factors affecting attitudes

Several factors may affect scientists' attitudes towards outreach. In their survey-based research conducted on scientists at the University of Manchester in the UK, Poliakoff and Webb (2007, p.254) found that "Past [behaviour] was clearly the most powerful predictor of [behavioural] intentions." Although the research reported in this thesis did not adopt the same methodology, the influence of past behaviour – in this case treated as "outreach experience" – was evident in the survey analysis and it was indeed identified as the most important factor. For example, those without outreach experience were more likely to agree with environmental constraints such as lack of time and report that their research was unsuitable of their research for outreach activities. They were also more likely to report a lack of communication skills among scientists (Table 4.16). The same scientists were more likely to rank all target groups for communication less favourably, although only the (negative) regression coefficients for "Groups for education" and "Groups related to research" were statistically significant (Table 4.20).

Andrews *et al.* (2005, p.281) found in their aforementioned study that the attitudes towards outreach involving education ("K-12") and the general public "varied by career stage, job type and gender". Since there were very few non-physicists responding to the survey, and because the student/non-student status of the respondents was the only consistent career-related information from the CMS database, variations with career stage and job type were not tested. However, the role of age was. The data show that younger scientists are more likely to agree with statements about the benefits of outreach (Table 4.12). On the other hand, the older the respondents were, the more positively they rated all of the audience except peer groups (Table 4.20). Older scientists appear to be more interested in dissemination and educational activities as well as audiences related to academia more generally They were, however, less interested in communicating with their peers. Age was not an influential factor for broader perceptions about outreach.

Evidence in the literature for the variance of attitudes by gender is mixed. For example, in their work on the attitudes towards outreach, conducted by survey and interviews of biologists and physicists across 20 graduate programmes in the USA, Ecklund, James and Lincoln (2012, p.2) find that "women are markedly more involved in outreach work than men". Conversely, Crettaz von Roten (2011), studying researchers at the University of Lausanne in Switzerland, found that women are less active than men when it comes to outreach for reasons such as the media contacting significantly fewer women scientists from the university. As demonstrated in the survey analysis (§ 4.1.4), although women responded in a slightly but significantly higher proportion, the self-reported rates of outreach participation between female and male scientists in CMS were almost identical.

Crettaz von Roten (2011) also found, however, that attitudes towards outreach were not significantly different between women and men. In this doctoral research study, gender did not have a significant relationship with most of the measures being studied. The two exceptions were benefits to society and societal obligations: women were more likely than men to agree with these groups of statements.

The majority of CMS scientists participate in outreach without being required to do so by their funding agencies (§ 4.1.5). Nevertheless, compared with those who were required to do outreach by their funders, those who reported explicitly *not* being required to do so were more likely to rate all audiences less favourably. The group who were unaware of their funders' requirements were also likely to rate the audiences less favourably but the relationship with only the "dissemination" group was statistically significant. Combining these data with the interviews, in which some scientists reported that the act of including outreach plans in their grant applications allowed them to reflect on their work and on outreach, we can speculate that the act of reporting your outreach plans to their funders may get scientists to view various communication audiences more favourably. The embedding of outreach participation in research grants is discussed in the next section.

6.3 Decoupling outreach and research grants

Funding bodies "are in a position to potentially influence science practice and [public engagement with science] specifically" (Palmer and Schibeci, 2014, p.512). As such, it is worth understanding if scientists are aware of any outreach requirements their funding agencies may place on them. Indeed, as shown above (§ 6.2), those required to participate in outreach rate all of the target groups for communication more favourably than their colleagues do. However, it is not clear why this should be the case, since CMS scientists collectively report to over 40 funding agencies in nearly as many countries, with differing requirements, in addition to diverse policies and terminologies associated with public engagement that vary with language.

Further, many of the survey respondents who are active in outreach were content with the status quo of either not being required to do outreach or not knowing *if* they are required. At the same time, some of the interviewees who were enthusiastic about outreach participation and were required to take part in it expressed scepticism about outreach being mandatory. The latter focused on two particular points: that not everyone is equipped with the skills or interest necessary to engage non-specialists and that larger collaborations are at a financial advantage being able to pool the fractions of overall grant resources assigned to outreach in order to hire professionals to facilitate public engagement.

Building on the theme "Access enhances participation", in particular balancing agency with centralisation (§ 5.2.3.2) and making outreach participation non-mandatory (§ 5.2.3.3), and the fact that the majority of CMS scientists participate in outreach without being formally required to do so, we can conclude that it is better to **make public engagement infrastructural** rather than compulsory. This idea is not new. The Royal Society, Research Councils UK and Wellcome Trust (2006, p.17) study made similar recommendations. They called for "a more effective support system for public engagement", "greater rewards and recognition for public engagement work" and "better coordination between organisations working on public engagement". This is mirrored in the interviews: many of the interviewees recognised the value of the communications training they received, some wished to include their outreach plans in grant applications even if they were told it would not be considered in making the decision, and others asked for more coordination between the various groups involved in particle-physics outreach.

6.4 Typology of public engagement in particle physics

The interview data shows that public engagement – or outreach – has diverse meanings within the particle-physics community, which is similar to the results of previous research (see, for example, the theme "Public engagement is multiple" in Davies (2013, pp.693–694)). Most meanings were associated with the "public communication" mechanism described by Rowe and Frewer (2005). The dominant treatment of outreach is as a didactic, information-transfer activity, meant to transfer information both about the specific research being done in particle physics and about the scientific method more generally. This is also demonstrated in the survey data, in the groups that the community favours for communication: university students, teachers and school students all ranked above the non-specialist public, government, media such as documentary makers, and general journalists. Most of the activities take place in educational settings and one interviewee said they would prioritise teachers over all other groups when it came to on-site visits at CERN. Researchers based at universities report outreach being used as a tool for the recruitment of students. This aligns with findings that the particle-physics community is one that "renews itself by training novices" Traweek (1992, p.74). These results are different from those reported by MORI (2000), although the methods used to ascertain the priorities differ slightly: where the previous study asked scientists to name the audiences they thought were important, this survey listed several potential audiences and asked for their importance, perceived knowledge about particle physics and perceived ease of communication to be rated on a 1–5 scale. Despite this, it is evident that education-focused groups were ranked higher in this research than in the previous study, where the general public, government and industry ranked higher than students.

The low ranking of industry stands out in particular, especially given the fact that CERN, for example, publishes Knowledge Transfer reports annually (e.g. CERN, 2020) that highlight the close ties with industry. This may be attributed to a few different reasons. Firstly, the MORI (2000) study included scientists who were directly funded by industry. This is almost never the case with particle physicists. In fact, Traweek (1992, p.4) reported that funding "is directly determined by national governments: no private sponsorship could maintain a field dependent on machines so massive and so constantly changing". Secondly, while the focus of the Knowledge Transfer team is indeed on communicating how CERN collaborates with industry, this mostly concerns the hardware experts among the physicists on the one hand and engineers on the other; engineers were very poorly represented in the survey and this *may* affect the low scores for industry. Further, despite a rich history of knowledge from (particle) physics being used to develop life-altering technologies, particle physics is not performed with applications in mind and so the opportunities for collaboration with industry may be lower.

Although non-specialists were rated in a particularly negative light on the attitude scales in the survey – described as having little understanding of what scientists do and lacking knowledge/education about science – some did agree in the survey that outreach could make them think about their own research differently. Some of the interviewees similarly expressed the view that participating in outreach had the potential to get them to critically reflect on their own research. In the same vein, the participatory and deliberative paradigms were discarded in both the survey and the interviews, with interviewees opposed to the idea that wider society should have an influence on how research funding is allocated. The fears expressed against referenda were particularly striking, given CERN's own history: ironically, the construction of CERN in Geneva itself needed approval by the local populace via a referendum in the 1950s.

Finally, outreach is also seen as a vehicle to cultivate an appreciation for sciences in general, to boost the public understanding of science. The scientists also seek to excite and inspire people, which is a characteristic of physicists in general (Dudo and Besley, 2016). Although particle physics is not regarded as having any direct or immediate relevance to everyday human life, the research is nonetheless described as a cultural practice, aligning with the cultural argument for teaching science that Osborne (2010, p.53) proposes: “The work of the best scientists is [...] just as creative as that of the best writers and artists.” The scientists are keen to emphasise the technological benefits that physics has provided, and some suggest that the best way for society to “be involved” in the research enterprise is to continue to champion its cause and sustain long-term financial support.

Chapter 7

Conclusions

In this thesis I have presented new findings on scientists' attitudes towards public engagement with science, or outreach. Areas of basic science are under-represented in science-in-society literature (Besley *et al.*, 2021), and this research has sought to remedy the situation by presenting the perspective of high-energy particle physics. The community of researchers in this field is fairly close-knit (Traweek, 1992), with a vast proportion of them conducting their research as part of international collaborations based at CERN, the European Organization for Nuclear Research, in the outskirts of Geneva, Switzerland. I have identified aspects of such collaborations that the scientists find particularly advantageous when it comes to outreach participation. Scientists in the field are active in outreach, and take part in such activities in great numbers even when not asked to do so by their funding agencies. Despite being a niche field, particle physics has captivated people from all over the world to the point where even technical presentations about discoveries made at CERN have been enthusiastically followed by wider society. The scientists have responded to this enthusiasm and are keen to share their research with the world, which many recognise as a cultural practice.

Below, I would like to introduce what I consider to be an important outcome of this research: the notion of "**relevance-distance**". I have spent several years mulling over this notion. I see it serving as a conceptual tool to evaluate the potential for various kinds of public engagement with a given field of research, in order to adopt a nuanced approach to ascertain the possibilities and limitations that each field has for public engagement.

7.1 Relevance-distance

I would like to address the term "public engagement with science and technology" – or PEST – itself. The data, mainly from the interviews but also from the survey reported in this thesis, call attention to a curious aspect of this paradigm of science communication. It pertains to the contrast in science-communication/STS scholarship of on the one hand noting that it is inappropriate to use the term "general public", given the many (often self-identifying) *publics* that are present in different contexts with varying levels of domain expertise, and on the other applying the enveloping term "science" to extremely heterogeneous fields of research, a phenomenon which has been acknowledged in science-communication scholarship (Bucchi and Trench, 2014; Holliman and Jensen, 2009).

To explore this inconsistency, we must examine the constituent terms of PEST closely. We put to one side the term "technology" as it is beyond the scope of this thesis, which is focused on fundamental research, and first consider the term "science". In the context of research and development (R&D), the OECD (2015, p.29) distinguishes between basic and applied research as follows:

> "**Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. **Applied research** is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective."

However, many prominent publications in science-communication and STS scholarship appear to focus exclusively on the latter. Areas of fundamental research are conspicuous by their extremely limited presence in scholarly literature on public engagement. Indeed, while questioning the very meaning of the term "science", Wynne remarks that when referring to the term the scholarship tends to refer to "its de-facto synonym, 'risk' " (Wynne, 2007, p.99), later using the term "uncertainty" as well. In the European context, the most worrying example – from this researcher's perspective – regarding basic sciences put to the side in public-engagement policy is a report published under the aegis of the European Commission that addresses "reactions to issues at the intersection of 'science' [. . .] and 'risk' " (Felt *et al.*, 2007, p.9). The report goes on to mention nanotechnology, medical sciences, neuroscience and genomics, but barely touches upon fields like physics (introduced in the context of nuclear power, for example) and chemistry (where it was brought in on matters of chemical safety), with other sciences like geology entirely ignored.

As the interviewees of this doctoral research project emphasise, particle physics in particular has very little, if any, direct or immediate relevance to day-to-day human life. The pursuit of knowledge of the fundamental laws of the universe is seen as a cultural practice with minimal risk, if any, to humanity or the environment, with some even going so far as to state that what they do can be seen as entertainment. It is worth quoting Fermilab's founding director Robert Wilson's testimony to the US Congress's Joint Committee on Atomic Energy in 1969, regarding the construction of the laboratory's first particle accelerator.* He was questioned about the value of the research to preserving the security of the country:

> "It only has to do with the respect with which we regard one another, the dignity of men, our love of culture. It has to do with those things.
>
> [. . .]
>
> "Are we good painters, good sculptors, great poets? I mean all the things that we really venerate and honour in our country and are patriotic about.
>
> "In that sense, this new knowledge has all to do with honour and country but it has nothing to do directly with defending our country except to help make it worth defending."

Indeed one of the interviewees evoked this notion in expressing an equivalence between particle physics and art (§ 5.2.6): "We can live without but we are a better society if we live with." This perspective is not exclusive to particle physics. Previous research has found that more generally "physicists and astronomers were more likely to say they [prioritise] communication designed to excite public audiences" (Dudo and Besley, 2016, p.9). The lack of immediate societal benefits also proves challenging to the scientists themselves, with research contrasting the attitudes of academic biologists and physicists towards outreach finding that "physicists [see] convincing the public of the legitimacy of their research as perhaps central to research funding for physics" (Ecklund, James and Lincoln, 2012, p.4).

Turning our attention to the term "public engagement", we can see that the obvious consequence of excluding – intentionally or otherwise – areas of basic or fundamental sciences from the purview of science-communication and STS scholarship is that the paradigms of science communication (be it "public understanding of science" or "public engagement with science and technology") that have developed claiming to apply to all sciences in reality only reflect the range of possibilities within more applied sciences. Perhaps unsurprisingly given the myriad socio-cultural contexts across the globe in

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* https://history.fnal.gov/historical/people/wilson_testimony.html

which science-in-society conversations play out, there appears to be no universally agreed-upon definition of public engagement. However, even more recent research that seeks to define the term appears to ignore the basic sciences, with a recent paper focused on CRISPR defining public engagement in relation, seemingly exclusively, to "the development of new technologies" (Scheufele *et al.*, 2021, p.1).

This has in turn led to a highly positive look at participation (Braun and Schultz, 2009) and to an orthodoxy within the study of science in society that maintains that early and deep "upstream" engagement with various stakeholders – be they patient groups and caregivers or the potential distributors and consumers of GMOs – enhances the robustness of the research being conducted. Although they have been questioned from different approaches by scholars over the years (Cooke and Kothari, 2001; Irwin, 2006; Nisbet and Scheufele, 2009), the dominant view is that these approaches, which are increasingly being driven under the banner of Responsible Research and Innovation, RRI, (Owen, Macnaghten and Stilgoe, 2012), seek to ensure that research design is informed by a diversity of views. This may be appropriate and indeed desirable when developing research into human disease or technologies such as robotics (Wilkinson, Bultitude and Dawson, 2011), the latter of which may have significant impacts on future employment for example, but becomes far more challenging for fields of fundamental research, which have their own idiosyncrasies. Indeed, "cultures of disciplines may influence cultures of outreach" (Johnson, Ecklund and Lincoln, 2014, p.91).

While deliberation can still play a valuable part in fields with far less applicability to day-to-day human life, the role of participatory engagement needs more careful examination as wider society may not necessarily be in a position to shape the research agenda or contribute to the research outcomes of fundamental sciences in a meaningful way. Many interviews reported in this thesis (§ 5.2.2) showed the reluctance of scientists pursuing particle physics to involve civic society in deliberations about their research funding and governance. Examples from Fermilab (Yurkewicz, 2004) show that deliberation with civic society tends to be done around the infrastructure of research projects. This can sometimes take the form of performing due diligence, and is typically done by senior researchers heading the organisation in question and who are specifically tasked with local-community engagement.

The lack of attention given to fundamental research in other scholarly work on the relationship between science and society highlights a gap in our understanding of public attitudes toward fields of fundamental research as well as of the possibilities of engagement with society. This research has attempted to shed light on this, but only concerns one field of fundamental research. Naïvely extending the expectations of participation (or deliberation) from fields of applied research to fundamental research severely limits our ability to effectively evaluate how science communication is performed across research areas (Reed *et al.*, 2018). The potential to engage with wider society around fundamental research may well be limited to conveying a sense of wonder and excitement (Dudo and Besley, 2016), and encouraging participation through volunteer-computing-based citizen-science initiatives (Nov, Arazy and Anderson, 2014; Vinsen and Thilker, 2013).

Studying how scientists in the UK conceptualise communicating with wider society, Davies notes that "the most important thing in public communication is to be relevant" (Davies, 2008, p.417), highlighting the difficulties of interesting people if the research is not directly applicable to them. As the interviews show (§ 5.2.5), particle physics is not relevant to people's lives in any direct or immediate way. Fundamental sciences, and subjects like particle physics in particular, thus face challenges associated with communicating research practices and outcomes that are unlike those experienced by fields with more practical consequences, and we should be careful to note these distinctions.

To consider the applicability of specific paradigms of public engagement to a given field of research, I introduce a concept known as "relevance-distance". The relative "relevance-distance" – the degree to which the field of research in question holds relevance to everyday human life – can be visualised on a two-dimensional pseudo-scale. The two dimensions, extending in positive directions along the X and Y axes from 0, represent directness and immediacy of relevance respectively. We can use this concept to explore how the particle-physics community conceptualises public engagement, though the concept could equally be tested with the public to understand their relationships with a variety fields of research, which would shed light on how publics might wish to engage with different research fields. A purely illustrative example, with no real data, is shown in Figure 7.1.

This pseudo-scale can be thought of as having a continuum of relevance to everyday human life, with "Proximal" relevance close to 0, "Intermediate" relevance being located around the diagonal shown on this imaginary scale, and "Remote" relevance located furthest from 0. These three areas correspond, broadly speaking, with three different kinds of scientific research:

- **Proximal**: Closest to being relevant to everyday human life are fields of research that specifically study human beings or their immediate surroundings. These include the areas of biomedical research, genetically modified organisms as well as climate science (independent of whether the public at large find these areas relevant to their lives), for example.
- **Intermediate**: Such fields of research do not concern themselves with human life per se, but may

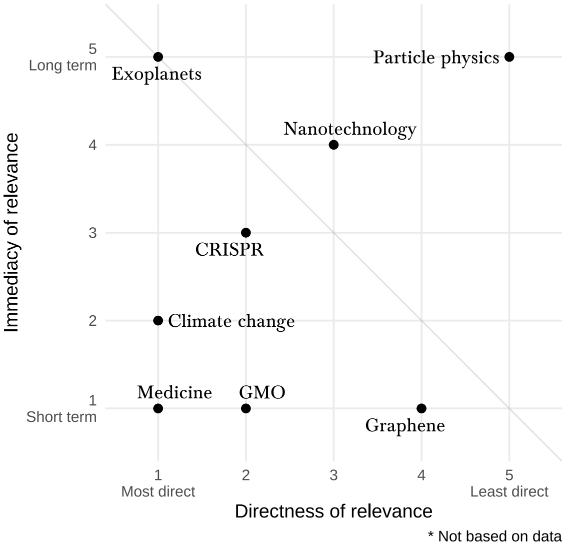

Figure 7.1: Illustrative representation of the concept of “relevance-distance”

either directly or immediately affect human society. These include fields such as nanotechnology or material sciences (graphene, for example), some of which are controversial and present specific challenges with regards to risk communication.

- **Remote**: Some fields of research – the fundamental sciences and pure mathematics, for example – concern themselves with seeking answers to basic questions about the universe and the laws that govern nature. While they certainly possess the potential to affect human life in a utilitarian way, the research is not performed with applications in mind.

The close relevance of fields such as medicine, allow researchers to clearly frame the potential impacts of their research (even if these are some distance away). For example, research into cures for different types of cancers is something most people can relate to in some way (even if the research is exploring something more fundamental, such as apoptosis – programmed cell death).

In looking at how particle physicists view their relationship with society (adopting, admittedly, a “science-and-society” approach instead of a “science-in-society” one), we can ascertain what “relevance-distance” is applicable to their field of research. Although such a self-assessment suffers from severe limitations and serves to reinforce beliefs held by the research community, it nevertheless helps us reflect on the nature of science-communication activities (and indeed public-engagement endeavours) that should be expected from this community, which can influence the way we evaluate the relationship between particle physics and wider society.

Statements such as those made by Robert Wilson, above, are not meant to preclude the possibility of future material applications arising from the pursuit of fundamental knowledge, but to highlight that the primary objective of these branches of research is not to develop applications or technology. Research in the fundamental sciences pushes the boundaries of available technologies, fostering close relations with industry in order to develop new tools and techniques, and results in unexpected spin-offs. For many of the interviewees (§ 5.2.5), particle physics, and fundamental physics more generally, derives its relevance from its spin-offs. Examples included (a) the study of electromagnetism and the resulting electrical revolution, (b) relativity and satellite communications, and (c) particle accelerators and novel cancer therapies. Yet, these spin-offs and applications are not why the research itself is done. They are often happy outcomes but do not serve as the primary motivation.

The preferred framing of public engagement within the particle-physics community is evident in the term chosen to represent such activities, namely "outreach". The term implies a reaching out to the wider public, suggesting that the public is elsewhere. At least one interviewee described public engagement thus: "Engagement in my view means going there and talking to them without expecting that they will come to you." This connotation does appear widely prevalent within the community, which expresses views largely consonant with a "deficit model" approach to science communication. Thus, the particle-physics community is inclined to rely on communication approaches that are more aligned to "deficit model" or one-way communication strategies, a model which Irwin (2014) reminds us can never be discarded in all contexts. Furthermore, the findings indicate that particle physicists largely feel that the public is not able to contribute to their research, and that they themselves do not particularly benefit (scientifically) from engagement with the public. Indeed, one of the interviewees remarked that research is ultimately a job, requiring training and experience: "I think they cannot really help like doing science because you need to have proper education and devote your time to it, it's a real job."

However, given the large relevance-distance for particle physics, I argue that "public understanding" approaches are not inappropriate and should not be dismissed in evaluating public engagement in this context. For the particle-physics community, public engagement seemingly adopts the BBC's motto of "inform, educate and entertain". Further, before embarking on the act of evaluating the possibilities for public engagement with a given field, we should use the pseudo-scale of relevance-distance and ask ourselves two questions: How direct is the relevance of the research to everyday human life? How immediate is the relevance of the research to everyday human life? Acknowledging that there is no universally applicable form of ideal public engagement helps us move away from treating research as involving homogeneous disciplines, and from "public engagement with science and technology" to "public engagement with *sciences* and *technologies*".

7.2 Implications and recommendations

There are three main implications of the research described in this thesis, with some recommendations to go with them.

1. The first concerns research into science communication (or science-in-society studies) itself, which must reflect on why scholarship in the field is so narrowly focused. The evolution of the field of PEST and STS research can only take place by ensuring that the paradigms that are espoused take into account a plurality of perspectives, this time from diverse fields of research. Indeed the primary recommendation is to formally reconstruct PEST as referring to *sciences* and *technologies*.

2. The next implication is for policy-makers and research funders. The notion that public engagement should be made infrastructural is not new (Royal Society, Research Councils UK and Wellcome Trust, 2006). However, this research shows that outreach-participation rates are not affected – at least in particle physics – by whether the scientists are required to take part or not. Not mandating outreach is not the same as not recognising it, though, and scientists should be encouraged to report both on their outreach plans in the future and activities they've undertaken in the past, without this being a requirement. The act of reflecting on the relationship of one's research with society as a consequence of including outreach plans in grant applications was found to be significantly related to viewing various groups within society more favourably.

3. Finally, and related to the previous point, funders around the world should consider the implications of the stated advantages of large collaborations in particle physics when it comes to outreach messaging and participation. There exists a perception within the particle-physics community that being part of a large collaboration makes outreach participation easy. Interviewees remarked that coordinated communication efforts by communication professionals made it possible to share outreach materials and resources, something which is difficult to do for small teams. Further, they rarely had to organise public-engagement events themselves. However, there are many reasons why particle physics is uniquely suited to such approaches, such as the fact that the research itself is concentrated at a few laboratories around the world, and the experiences may not translate well. Fields such as climate science and AI research should explore whether they would benefit

from supranational bodies facilitating outreach for researchers worldwide and creating a unified strategic narrative.

7.3 Limitations

This research was performed thoroughly, using well-established mixed-methods approaches, and its findings have provided new knowledge in the field of science-communication research. There are however some limitations, some of which can be addressed in future research.

Firstly, although the 11 duplicate responses from the survey participants were stable (see § C.1), and the survey data collected are thus valid, surveys on their own cannot account for social-desirability biases leading to people reporting answers that they *think* are what they should be reporting. While this is something that can be explored in personal interviews using qualitative methods, it was not foreseen to be part of the research protocol at the time.

Similarly, we cannot determine whether the large number of survey respondents reporting outreach experience is proportional to the overall CMS membership. That is, we cannot say whether around 90% of all CMS members have participated in outreach or whether those who are interested in outreach chose to respond to the survey in larger numbers than those who are not interested in it.

Finally, both the survey and the interviews did not get adequate (or any) responses from several of the groups that might have provided unique perspectives. These include certain countries that were under-represented in the survey as well, more generally, as the engineers within the CMS collaboration. Future research should focus on sampling strategies that ensure data from such groups are also available.

7.4 Future directions for research

Our knowledge of the attitudes that scientists have towards public engagement remains limited. This research has shed considerable light on an otherwise dark corner in the metaphorical bookshelf of science-in-society scholarship. However, there remain a few unanswered questions. The study of attitudes within the particle-physics community would benefit from a bigger study involving even more of the 37,000-odd researchers who submit particle-physics papers to the shared online repository, INSPIRE. In addition, given that the attitudes towards outreach seem to be clearly positive, future research should ask *how* positive the attitudes are, rather than asking *if* the attitudes are positive. Future research could also take the form of a longitudinal study to understand how attitudes evolve and how they are influenced by context: after all, CERN is only one of many laboratories where research collaborations gather.

We are also missing voices of the various publics who are interested in particle physics. While Florio and Giffoni (2020) have shown that societies are willing to support the research, it is worth examining what about the research is valued by wider society. CERN's open days, which take place every five to six years, have received around 70,000 visitors over a weekend in the past. I recall visitors from the Middle East and from North America visiting Geneva just for the weekend to be part of the event. Although a biased source of data, interviewing these visitors or having them fill short questionnaires would provide new knowledge on why people follow particle physics in their lives.

A third direction of future research concerns other research collaborations. Although they may not number as many as the CMS and ATLAS collaborations, researchers in astronomy also work in large, multinational teams often located at dedicated research centres. Similar research to the kind presented in this thesis would identify whether the attitudes vary across research communities, and would also help determine whether particle physics has a unique advantage with regards to the size of its major collaborations.

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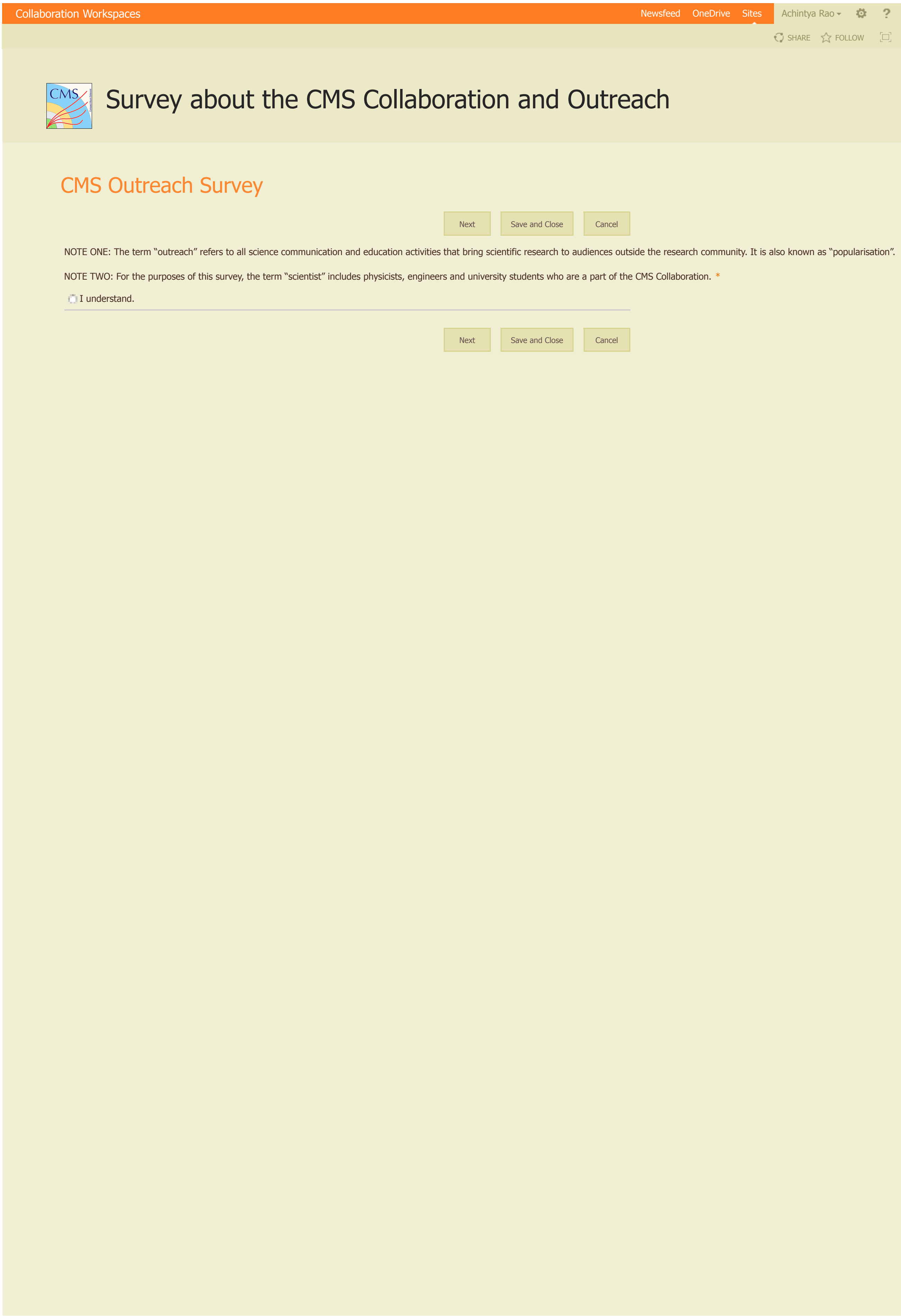
Appendices

Appendix A

Final survey questionnaire

These are screenshots of the final survey as they appeared on the web.



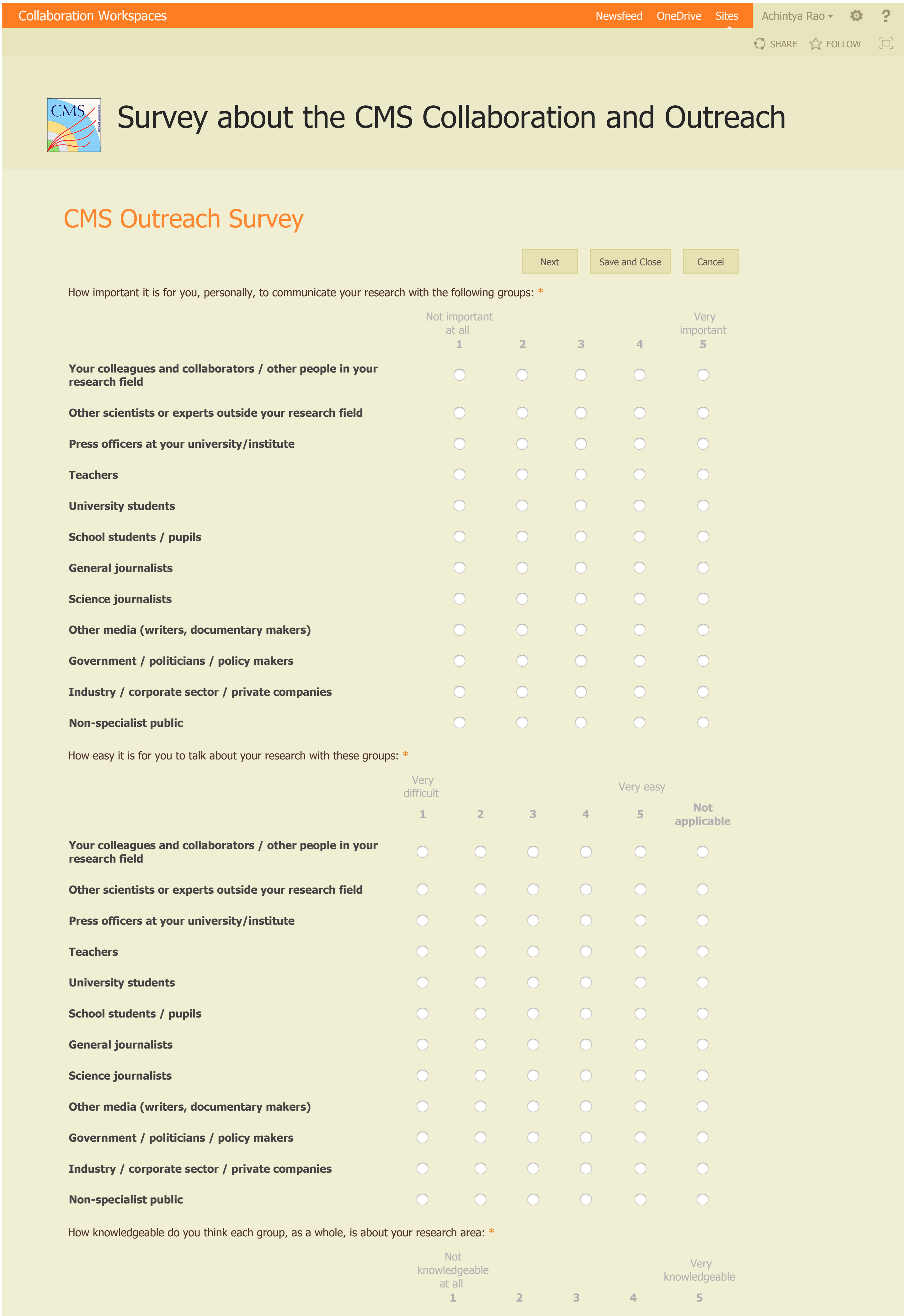
Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

NOTE ONE: The term “outreach” refers to all science communication and education activities that bring scientific research to audiences outside the research community. It is also known as “popularisation”.

NOTE TWO: For the purposes of this survey, the term “scientist” includes physicists, engineers and university students who are a part of the CMS Collaboration. *

○ I understand.



Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

How important it is for you, personally, to communicate your research with the following groups: *

	Not important at all 1	2	3	4	Very important 5
Your colleagues and collaborators / other people in your research field	○	○	○	○	○
Other scientists or experts outside your research field	○	○	○	○	○
Press officers at your university/institute	○	○	○	○	○
Teachers	○	○	○	○	○
University students	○	○	○	○	○
School students / pupils	○	○	○	○	○
General journalists	○	○	○	○	○
Science journalists	○	○	○	○	○
Other media (writers, documentary makers)	○	○	○	○	○
Government / politicians / policy makers	○	○	○	○	○
Industry / corporate sector / private companies	○	○	○	○	○
Non-specialist public	○	○	○	○	○

How easy it is for you to talk about your research with these groups: *

	Very difficult 1	2	3	4	Very easy 5	**Not applicable**
Your colleagues and collaborators / other people in your research field	○	○	○	○	○	○
Other scientists or experts outside your research field	○	○	○	○	○	○
Press officers at your university/institute	○	○	○	○	○	○
Teachers	○	○	○	○	○	○
University students	○	○	○	○	○	○
School students / pupils	○	○	○	○	○	○
General journalists	○	○	○	○	○	○
Science journalists	○	○	○	○	○	○
Other media (writers, documentary makers)	○	○	○	○	○	○
Government / politicians / policy makers	○	○	○	○	○	○
Industry / corporate sector / private companies	○	○	○	○	○	○
Non-specialist public	○	○	○	○	○	○

How knowledgeable do you think each group, as a whole, is about your research area: *

	Not knowledgeable at all 1	2	3	4	Very knowledgeable 5

Your colleagues and collaborators / other people in your research field	○	○	○	○	○
Other scientists or experts outside your research field	○	○	○	○	○
Press officers at your university/institute	○	○	○	○	○
Teachers	○	○	○	○	○
University students	○	○	○	○	○
School students / pupils	○	○	○	○	○
General journalists	○	○	○	○	○
Science journalists	○	○	○	○	○
Other media (writers, documentary makers)	○	○	○	○	○
Government / politicians / policy makers	○	○	○	○	○
Industry / corporate sector / private companies	○	○	○	○	○
Non-specialist public	○	○	○	○	○

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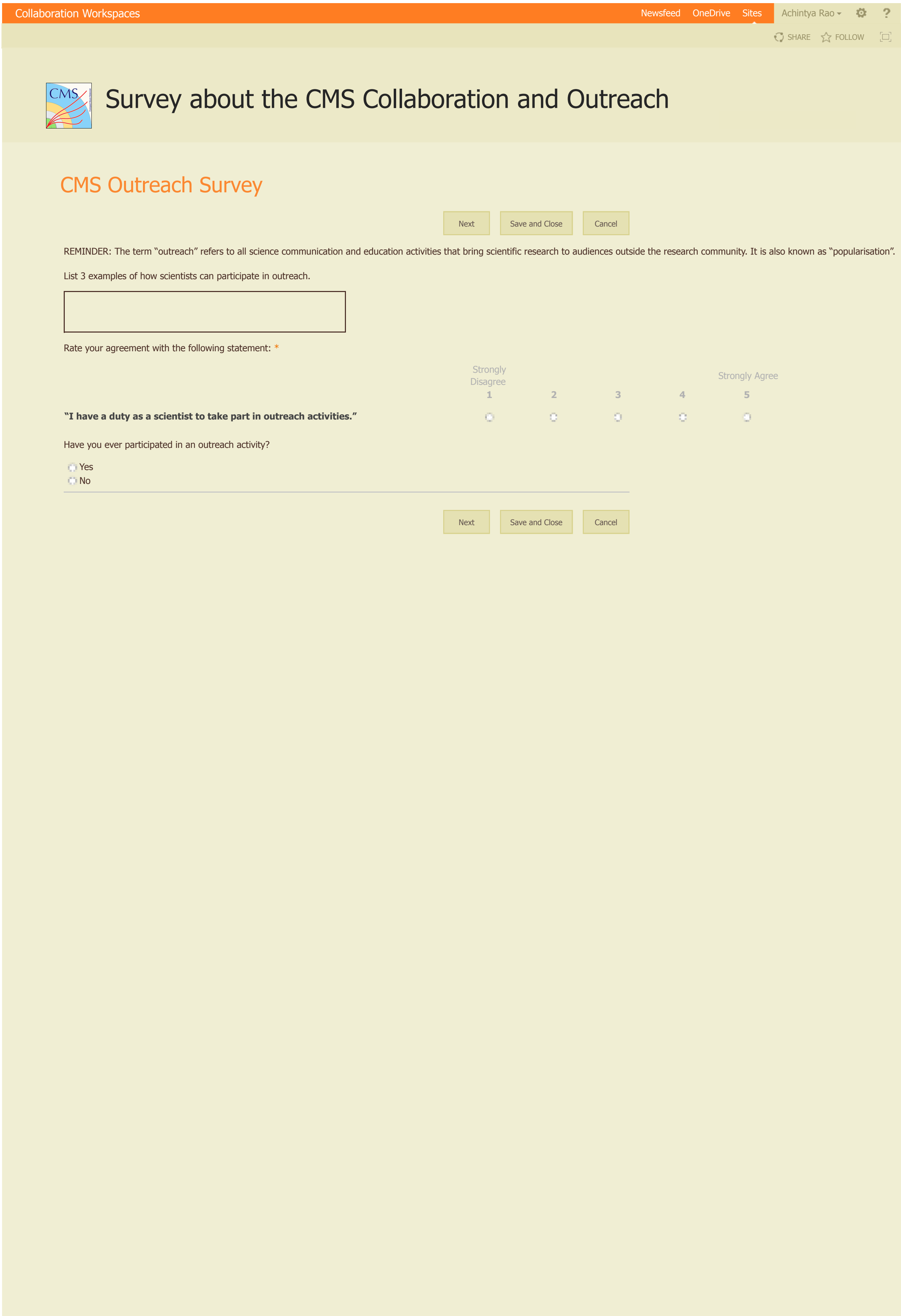


Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

REMINDER: The term “outreach” refers to all science communication and education activities that bring scientific research to audiences outside the research community. It is also known as “popularisation”.

List 3 examples of how scientists can participate in outreach.

Rate your agreement with the following statement: *

	Strongly Disagree 1	2	3	4	Strongly Agree 5
“I have a duty as a scientist to take part in outreach activities.”	○	○	○	○	○

Have you ever participated in an outreach activity?

○ Yes
○ No

Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

Please give examples of outreach activities you have participated in (list up to 3):

How many individual outreach activities have you participated in during the last 12 months?

○ 0
○ 1–5
○ 6–10
○ 11–50
○ 51–100
○ >100

How much time have you spent on outreach activities during the last 12 months?

○ None
○ Up to 10 hours in total
○ Up to 2 hours per month, on average
○ Up to 1 hour per week, on average
○ Up to 8 hours per week, on average
○ More than 8 hours per week, on average

How many of the outreach activities you participated in were in your native language?

○ None
○ A few
○ About half
○ Most
○ All

Please rate your agreement with the following statement: *

	Strongly Disagree 1	2	3	4	Strongly Agree 5
"I will only participate in an outreach activity if it is in my native language."	○	○	○	○	○

Pick the statement that you agree with the most: *

○ "I plan to participate in an outreach activity in the next 12 months."
○ "I do not plan to participate in an outreach activity in the next 12 months."
○ "I may participate in an outreach activity in the next 12 months."

Survey about the CMS Collaboration and Outreach

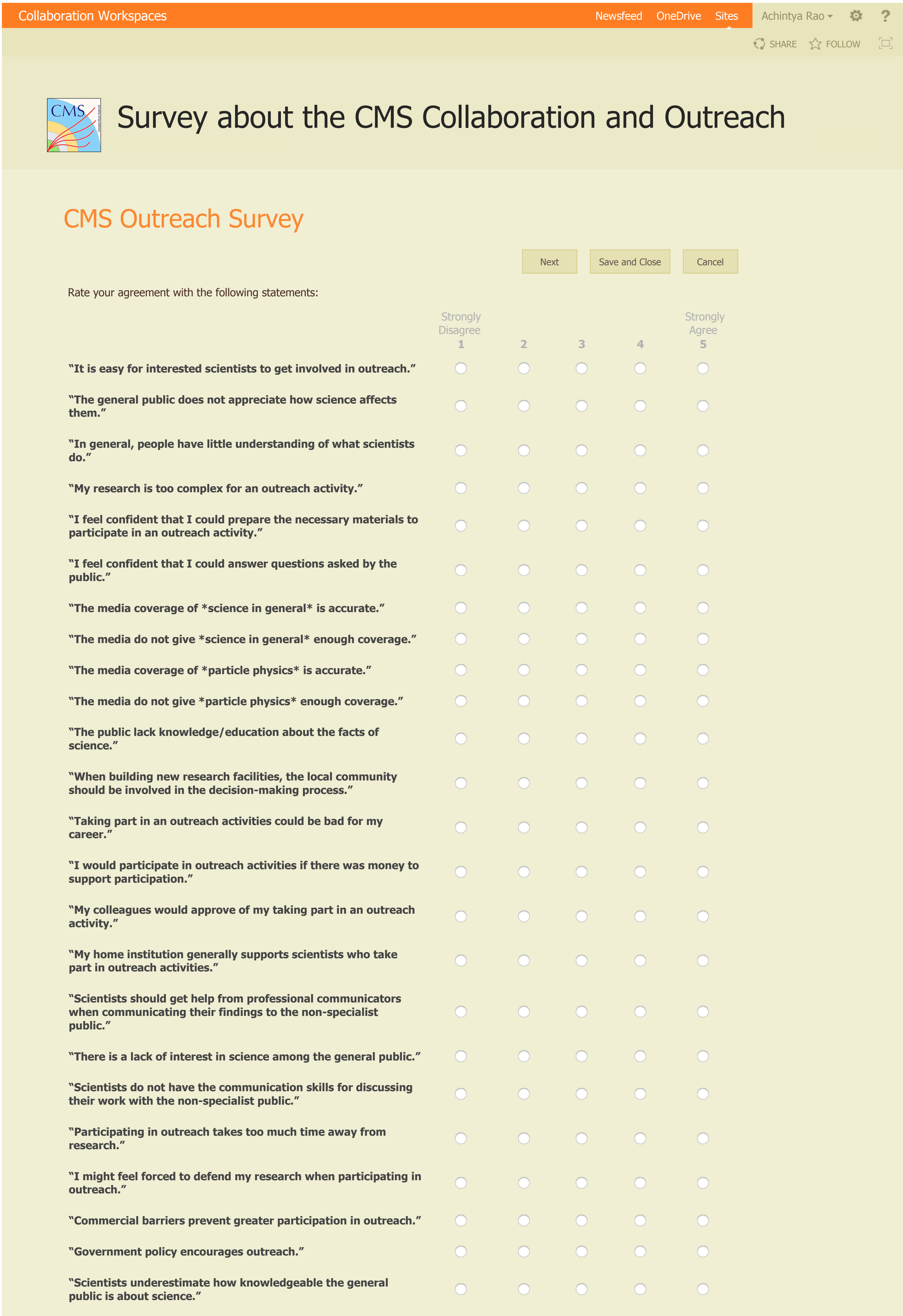
CMS Outreach Survey

Think about the personal benefits of participating in outreach, and rate your agreement with the following statements:

	Strongly Disagree 1	2	3	4	Strongly Agree 5
“It gives me experience in communicating my research.”	○	○	○	○	○
“It gets my name known.”	○	○	○	○	○
“It attracts research funding.”	○	○	○	○	○
“It advances my career.”	○	○	○	○	○
“I get a feeling of enjoyment.”	○	○	○	○	○
“It gives me job satisfaction.”	○	○	○	○	○
“It is an opportunity for others to contact me for collaborative purposes.”	○	○	○	○	○
“It shapes the direction of my research or makes me think about it in new ways.”	○	○	○	○	○
“It makes me a better scientist.”	○	○	○	○	○

Think about the benefits to wider society from outreach activities, and rate your agreement with the following statements:

	Strongly Disagree 1	2	3	4	Strongly Agree 5
“The public gets better knowledge/understanding of science.”	○	○	○	○	○
“It enables the public to judge scientific issues for themselves.”	○	○	○	○	○
“It enables the public to make informed decisions about their lives.”	○	○	○	○	○
“It helps improve the understanding of what scientists do.”	○	○	○	○	○
“There is less opposition to scientific research.”	○	○	○	○	○
“More people enter science education/science careers as a result.”	○	○	○	○	○
“Policy-makers are better equipped to make decisions.”	○	○	○	○	○
“Non-specialists can participate in scientific research.”	○	○	○	○	○
“Society can make informed decisions about research funding.”	○	○	○	○	○



Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

Rate your agreement with the following statements:

	Strongly Disagree 1	2	3	4	Strongly Agree 5
“It is easy for interested scientists to get involved in outreach.”	○	○	○	○	○
“The general public does not appreciate how science affects them.”	○	○	○	○	○
“In general, people have little understanding of what scientists do.”	○	○	○	○	○
“My research is too complex for an outreach activity.”	○	○	○	○	○
“I feel confident that I could prepare the necessary materials to participate in an outreach activity.”	○	○	○	○	○
“I feel confident that I could answer questions asked by the public.”	○	○	○	○	○
“The media coverage of *science in general* is accurate.”	○	○	○	○	○
“The media do not give *science in general* enough coverage.”	○	○	○	○	○
“The media coverage of *particle physics* is accurate.”	○	○	○	○	○
“The media do not give *particle physics* enough coverage.”	○	○	○	○	○
“The public lack knowledge/education about the facts of science.”	○	○	○	○	○
“When building new research facilities, the local community should be involved in the decision-making process.”	○	○	○	○	○
“Taking part in an outreach activities could be bad for my career.”	○	○	○	○	○
“I would participate in outreach activities if there was money to support participation.”	○	○	○	○	○
“My colleagues would approve of my taking part in an outreach activity.”	○	○	○	○	○
“My home institution generally supports scientists who take part in outreach activities.”	○	○	○	○	○
“Scientists should get help from professional communicators when communicating their findings to the non-specialist public.”	○	○	○	○	○
“There is a lack of interest in science among the general public.”	○	○	○	○	○
“Scientists do not have the communication skills for discussing their work with the non-specialist public.”	○	○	○	○	○
“Participating in outreach takes too much time away from research.”	○	○	○	○	○
“I might feel forced to defend my research when participating in outreach.”	○	○	○	○	○
“Commercial barriers prevent greater participation in outreach.”	○	○	○	○	○
“Government policy encourages outreach.”	○	○	○	○	○
“Scientists underestimate how knowledgeable the general public is about science.”	○	○	○	○	○

“I would not be taken seriously as a scientist by the public if I participate in outreach.”	○	○	○	○	○
“To communicate with the public, I have to overly simplify my work, which reduces its scientific correctness.”	○	○	○	○	○

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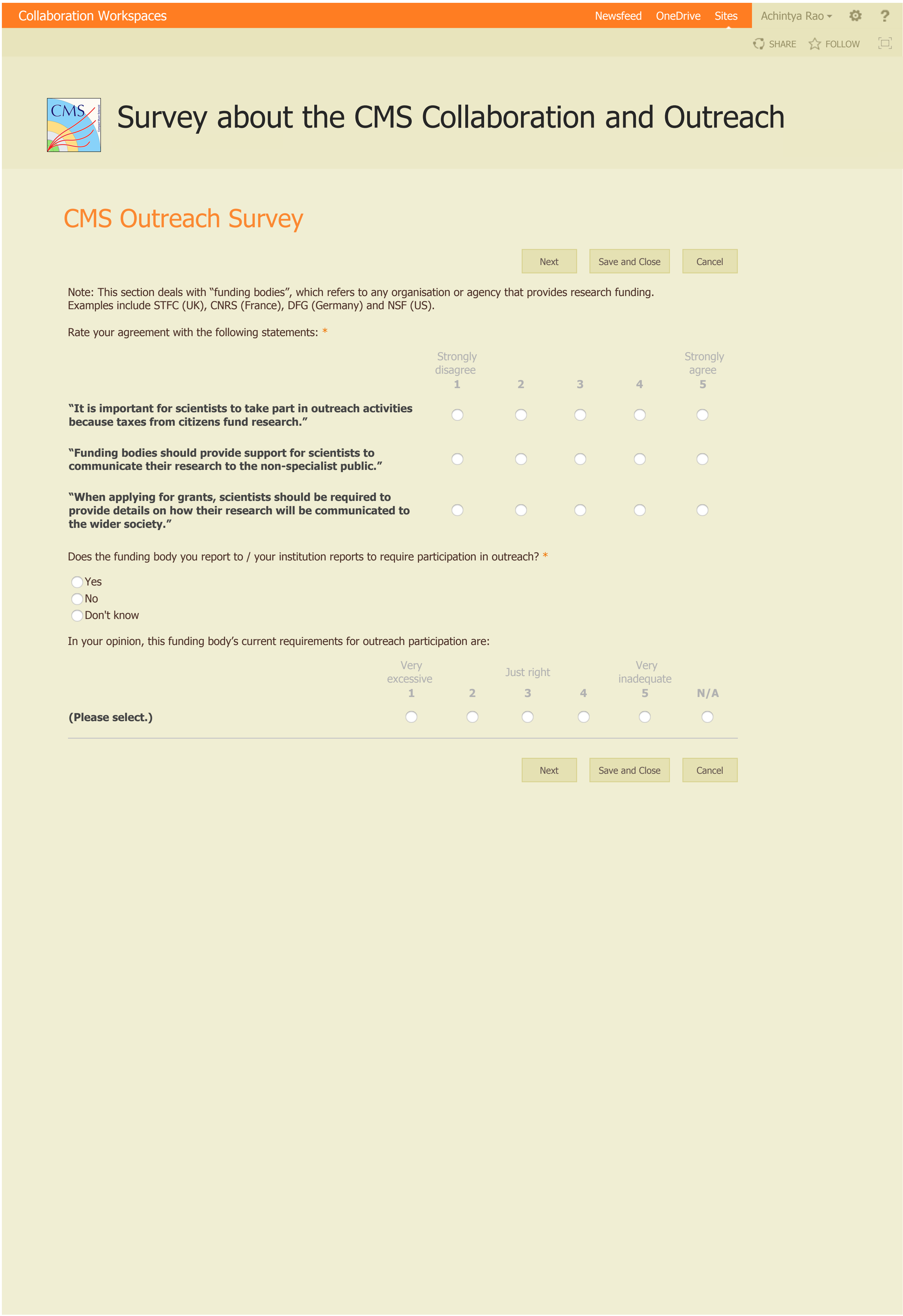


Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

Note: This section deals with “funding bodies”, which refers to any organisation or agency that provides research funding. Examples include STFC (UK), CNRS (France), DFG (Germany) and NSF (US).

Rate your agreement with the following statements: *

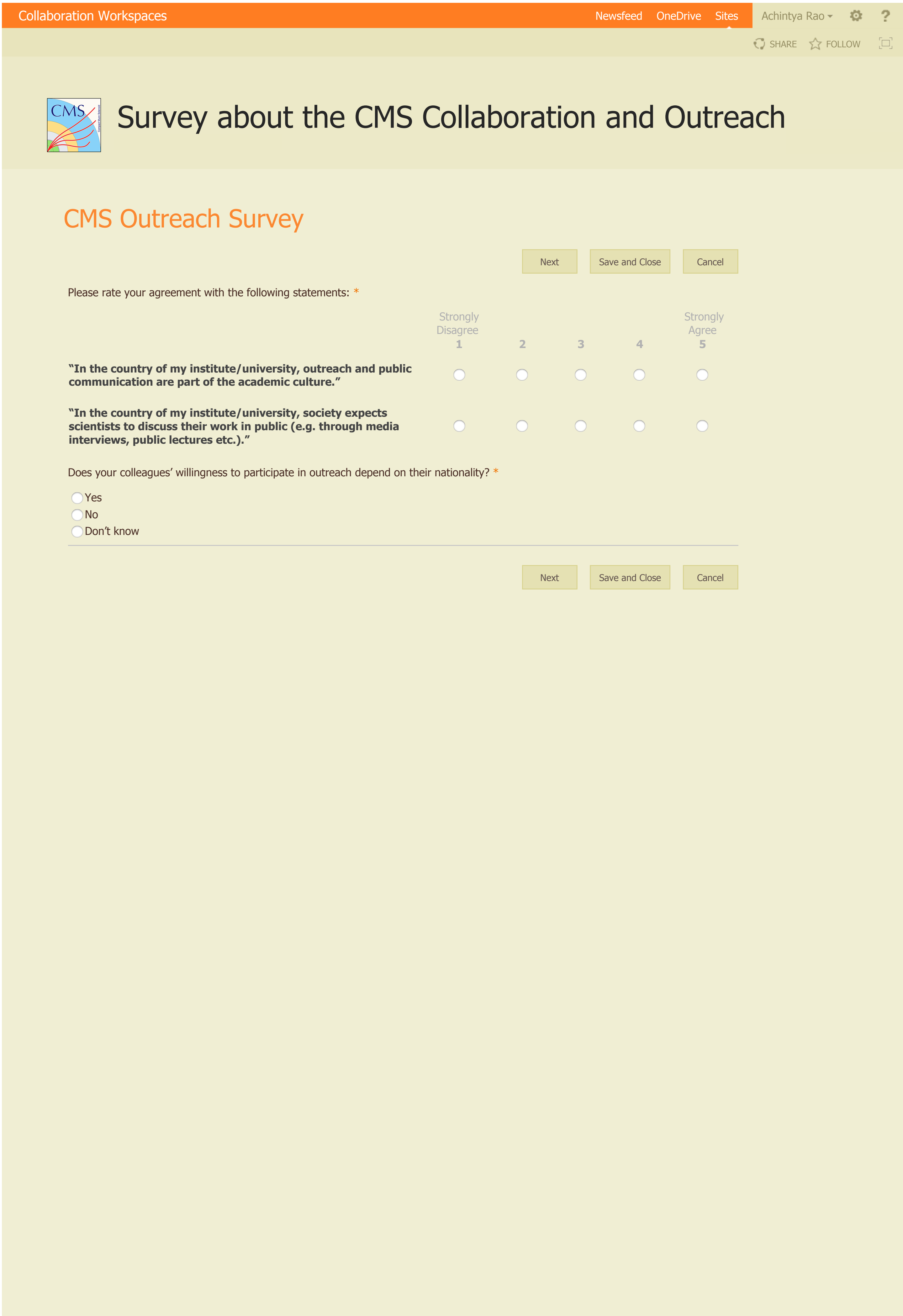
	Strongly disagree 1	2	3	4	Strongly agree 5
“It is important for scientists to take part in outreach activities because taxes from citizens fund research.”	○	○	○	○	○
“Funding bodies should provide support for scientists to communicate their research to the non-specialist public.”	○	○	○	○	○
“When applying for grants, scientists should be required to provide details on how their research will be communicated to the wider society.”	○	○	○	○	○

Does the funding body you report to / your institution reports to require participation in outreach? *

○ Yes
○ No
○ Don't know

In your opinion, this funding body’s current requirements for outreach participation are:

	Very excessive 1	2	Just right 3	4	Very inadequate 5	N/A
(Please select.)	○	○	○	○	○	○



Survey about the CMS Collaboration and Outreach

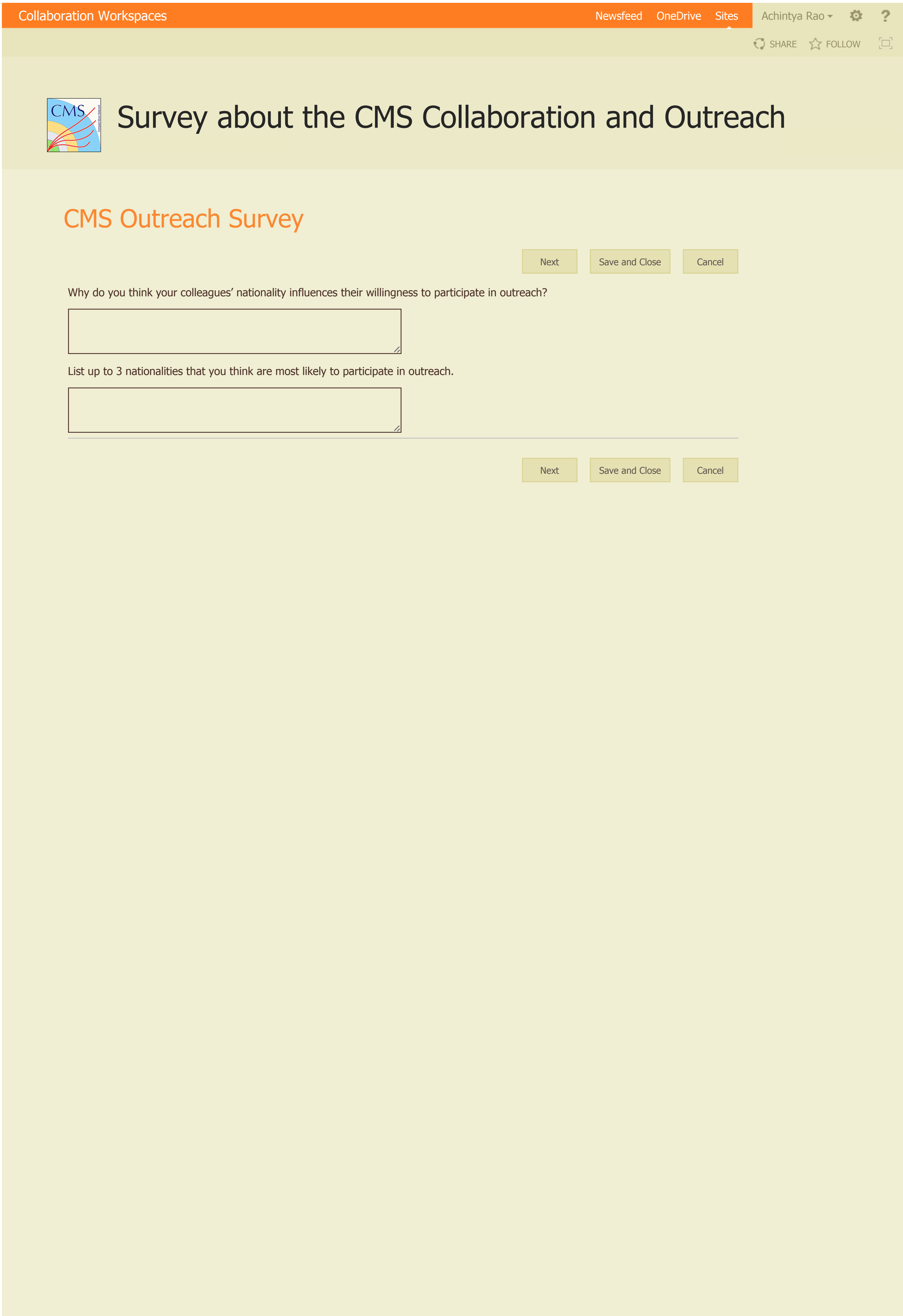
CMS Outreach Survey

Please rate your agreement with the following statements: *

	Strongly Disagree 1	2	3	4	Strongly Agree 5
"In the country of my institute/university, outreach and public communication are part of the academic culture."	○	○	○	○	○
"In the country of my institute/university, society expects scientists to discuss their work in public (e.g. through media interviews, public lectures etc.)."	○	○	○	○	○

Does your colleagues' willingness to participate in outreach depend on their nationality? *

○ Yes
○ No
○ Don't know

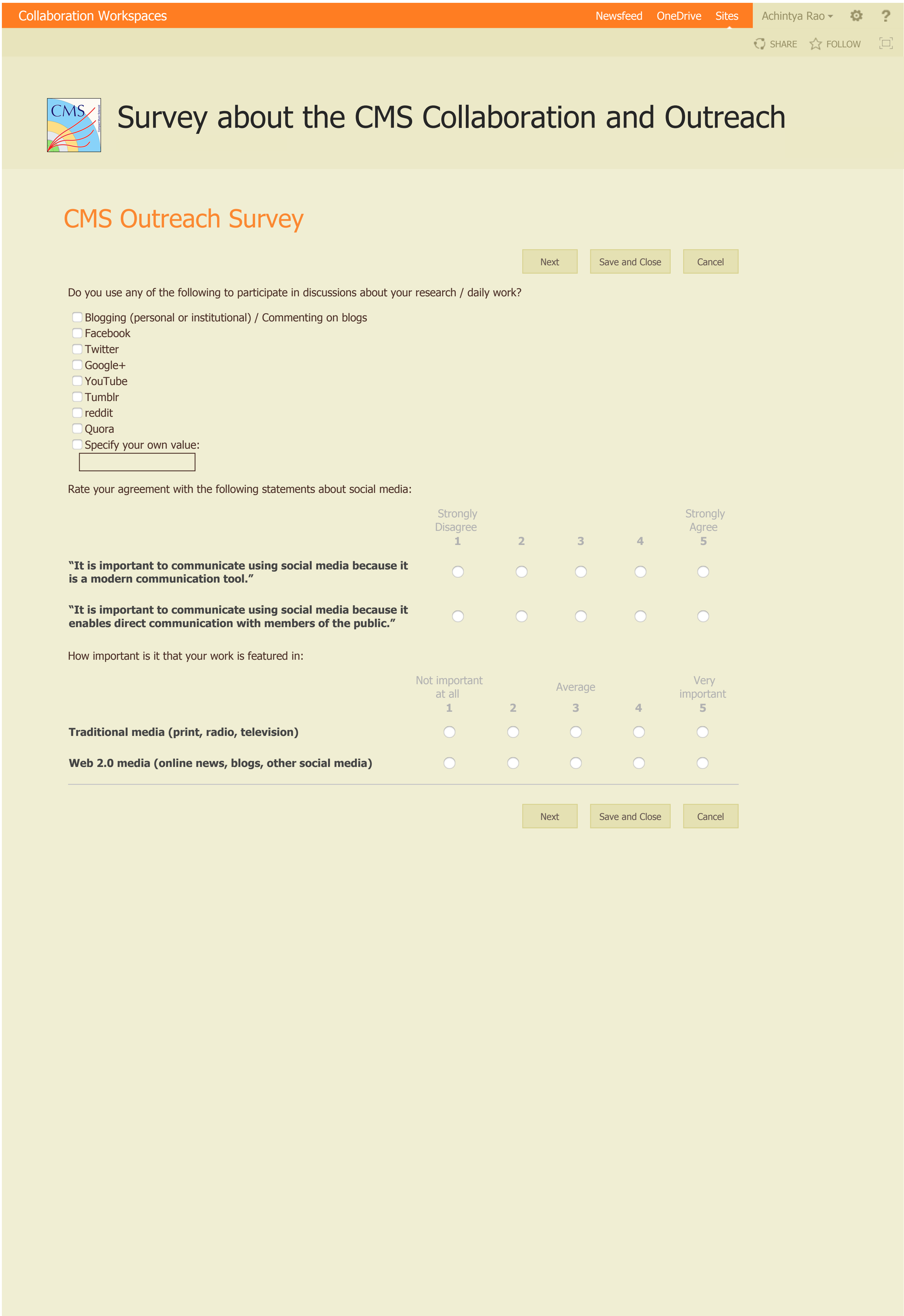


Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

Why do you think your colleagues’ nationality influences their willingness to participate in outreach?

List up to 3 nationalities that you think are most likely to participate in outreach.



Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

Do you use any of the following to participate in discussions about your research / daily work?

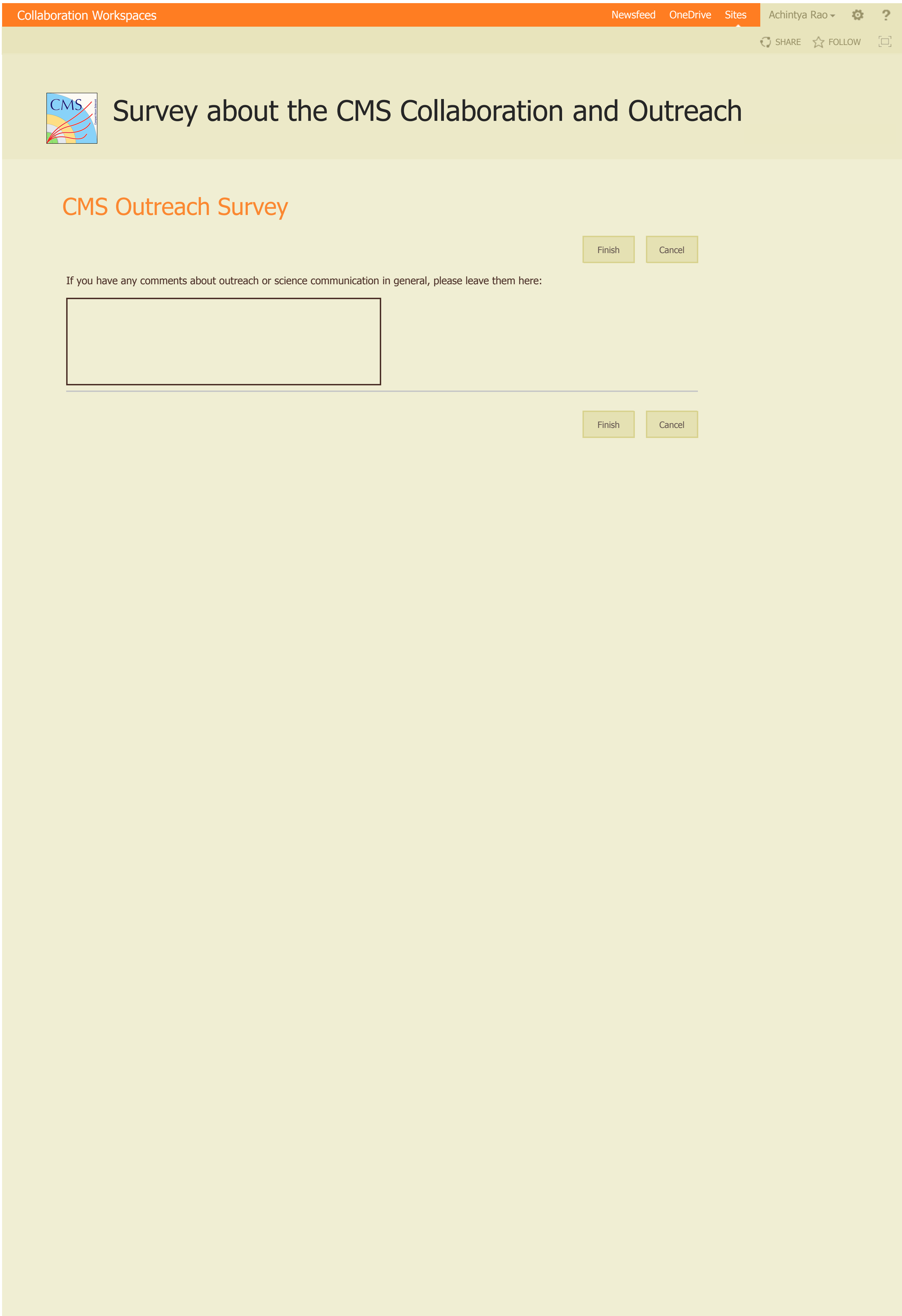
☐ Blogging (personal or institutional) / Commenting on blogs
☐ Facebook
☐ Twitter
☐ Google+
☐ YouTube
☐ Tumblr
☐ reddit
☐ Quora
☐ Specify your own value:

Rate your agreement with the following statements about social media:

	Strongly Disagree 1	2	3	4	Strongly Agree 5
“It is important to communicate using social media because it is a modern communication tool.”	○	○	○	○	○
“It is important to communicate using social media because it enables direct communication with members of the public.”	○	○	○	○	○

How important is it that your work is featured in:

	Not important at all 1	2	Average 3	4	Very important 5
Traditional media (print, radio, television)	○	○	○	○	○
Web 2.0 media (online news, blogs, other social media)	○	○	○	○	○



Survey about the CMS Collaboration and Outreach

CMS Outreach Survey

If you have any comments about outreach or science communication in general, please leave them here:

Appendix B

Interview questions

These are the questions that the scientists were asked in their personal interviews.

General

- [ ] In science communication, what does the term "public engagement" mean to you?
- [ ] What do you see as the main purpose of communicating particle physics with the public?
- [ ] Is there any aspect of particle physics that you think is particularly important to discuss with the public?

Society

- [ ] Do you think particle physics is relevant to people's lives? If so, how?
- [ ] Public engagement with research includes involving members of wider society in scientific research. Do you think members of wider society – i.e. those who aren't particle physicists – can play a role in particle-physics research?

Funding and Governance

- [ ] Have you ever had to include your outreach plans when applying for a grant?
  - [ ] If **YES**, how did you like the experience?
  - [ ] If **YES**, do you think it is valuable to include outreach plans in grant applications?
  - [ ] If **YES**, has the requirement to include outreach plans in a grant application influenced your view of outreach?
- [ ] Should large public projects require scrutiny by and discussions with the general public before they are approved? Why / why not?

International Collaboration

- [ ] Have you ever worked for an institution "away from your home country"?
  - [ ] If **YES**, has working at an institution "away from your home country" influenced your willingness to participate in outreach?
  - [ ] If **YES**, do you perceive different attitudes towards outreach at your "away-from-home" institution compared with your home country?
- [ ] **For those whose mother tongue is NOT English**:
  - [ ] What is the equivalent word for "outreach" in your primary/native/first language?
  - [ ] Do you face particular issues in communicating particle physics in your home country / native language? If so, what are they?
- [ ] What differences, if any, do you see with the way outreach is done in a large, international collaboration compared with smaller research groups or individual institutions?
  - [ ] What is your view of CERN's approach to outreach?
  - [ ] Does CERN's approach differ from that of your home institute?

    - [ ] Do you participate more in outreach activities when you are at CERN compared with when you are not at CERN? Why / why not?

Communication Feedback

- [ ] How do you rate the media coverage of particle physics?
- [ ] How do you rate the way particle physicists communicate their research?
- [ ] What problems, if any, do you see with the way particle physics is communicated by scientists?

Misc.

- [ ] Do you think doing outreach has changed the way you communicate your work with your peers?
    - [ ] If **YES**, how?
    - [ ] If **NO**, why not?
- [ ] **To those who have never participated before but said they would/might**: Since you filled the survey, have you participated in any outreach activity?
    - [ ] If **YES**, what did you do?
    - [ ] If **NO**, could you think of why you were unable to?

Appendix C

Additional tables and plots

C.1 Duplicate responses

Eleven people responded to the online survey twice, several weeks apart. The responses to 90 survey questions with Likert-type rating data were used to check if the responses had changed considerably on the second occasion. Of the total of 990 new variables in total (obtained by combining the number of variables with the number of responses), 40 were removed because either the second or the first instance had no responses recorded. The difference between the two responses was then calculated and plotted, as shown in Figure C.1. We can see that more than half the responses remained unchanged, while most of the ones that did change either increased or decreased by 1. This lends confidence to the provenance of the data and to the subsequent analysis.

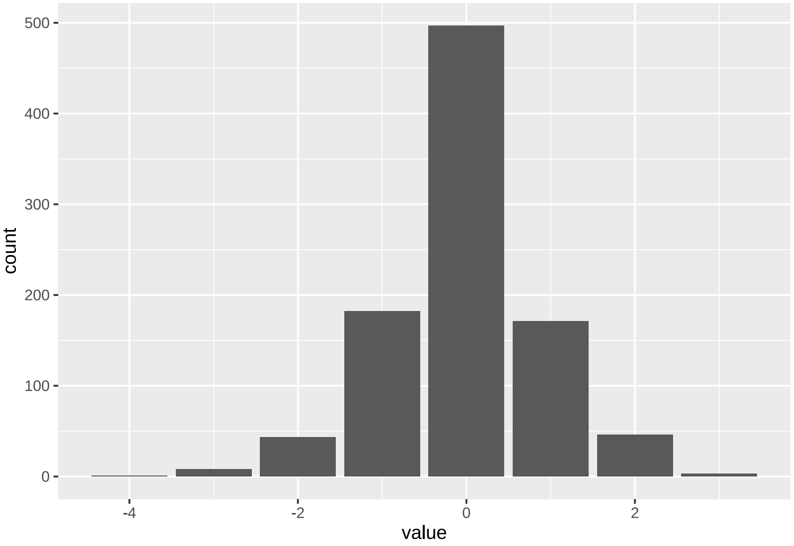


Figure C.1: Differences between the first and second replies to Likert-type data

C.2 Mean and median of audience favourability

The mean and median values for the overall ratings for audience favourability (see Figure 4.15) are shown in Table C.1.

Table C.1: Mean and median of audience favourability

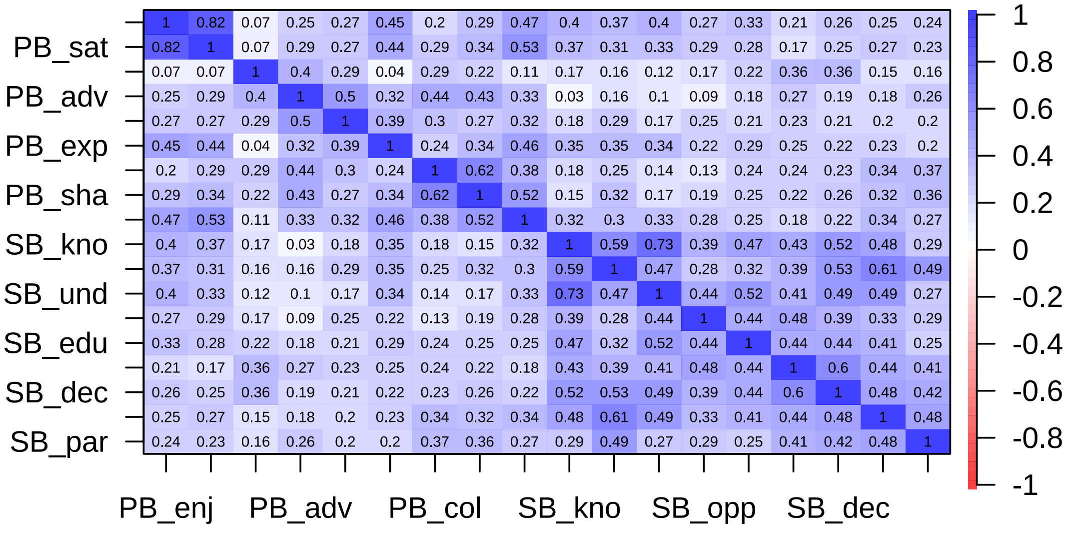
Audience	Mean	Median
Colleagues	14.04	9 > 15 > 15
Other scientists	11.07	4 > 11 > 15
University students	10.92	4 > 11 > 15
Science journalists	9.82	2 > 10 > 15
Teachers	9.75	2 > 10 > 15
School students	8.89	2 > 9 > 14
Press officers	8.65	2 > 9 > 15
Non-specialist public	8.24	2 > 8 > 14
Government	7.81	2 > 8 > 14
Other media	7.53	2 > 8 > 14
Industry	7.42	2 > 7 > 14
General journalists	7.12	2 > 7 > 14

C.3 Statistics and correlation plots

Please see Table 4.9 for an explanation of the IDs.

Table C.2: Descriptive statistics for all variables associated with outreach benefits

id	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
PB_enj	1	388	4.07	1.01	4	4.23	1.48	1	5	4	-1.22	1.25	0.05
PB_sat	2	388	3.98	1.01	4	4.12	1.48	1	5	4	-1.03	0.75	0.05
PB_fnd	3	389	3.05	1.12	3	3.08	1.48	1	5	4	-0.16	-0.72	0.06
PB_adv	4	388	2.45	1.11	2	2.38	1.48	1	5	4	0.39	-0.56	0.06
PB_nam	5	389	2.65	1.04	3	2.63	1.48	1	5	4	0.29	-0.52	0.05
PB_exp	6	389	4.39	0.85	5	4.54	0.00	1	5	4	-1.39	1.61	0.04
PB_col	7	384	2.97	1.20	3	2.96	1.48	1	5	4	0.05	-0.86	0.06
PB_sha	8	386	2.95	1.25	3	2.94	1.48	1	5	4	0.10	-0.98	0.06
PB_btr	9	386	3.66	1.14	4	3.77	1.48	1	5	4	-0.62	-0.33	0.06
SB_kno	10	389	4.43	0.73	5	4.56	0.00	1	5	4	-1.39	2.42	0.04
SB_jud	11	389	3.46	1.09	4	3.50	1.48	1	5	4	-0.30	-0.61	0.06
SB_und	12	389	4.33	0.74	4	4.45	1.48	1	5	4	-1.08	1.37	0.04
SB_opp	13	389	3.67	0.98	4	3.75	1.48	1	5	4	-0.48	-0.10	0.05
SB_edu	14	387	3.86	0.84	4	3.89	1.48	1	5	4	-0.35	-0.38	0.04
SB_pol	15	387	3.40	1.12	4	3.46	1.48	1	5	4	-0.39	-0.59	0.06
SB_dec	16	386	3.35	1.07	3	3.39	1.48	1	5	4	-0.24	-0.44	0.05
SB_liv	17	388	3.05	1.11	3	3.04	1.48	1	5	4	0.01	-0.69	0.06
SB_par	18	389	2.51	1.08	2	2.44	1.48	1	5	4	0.46	-0.37	0.05



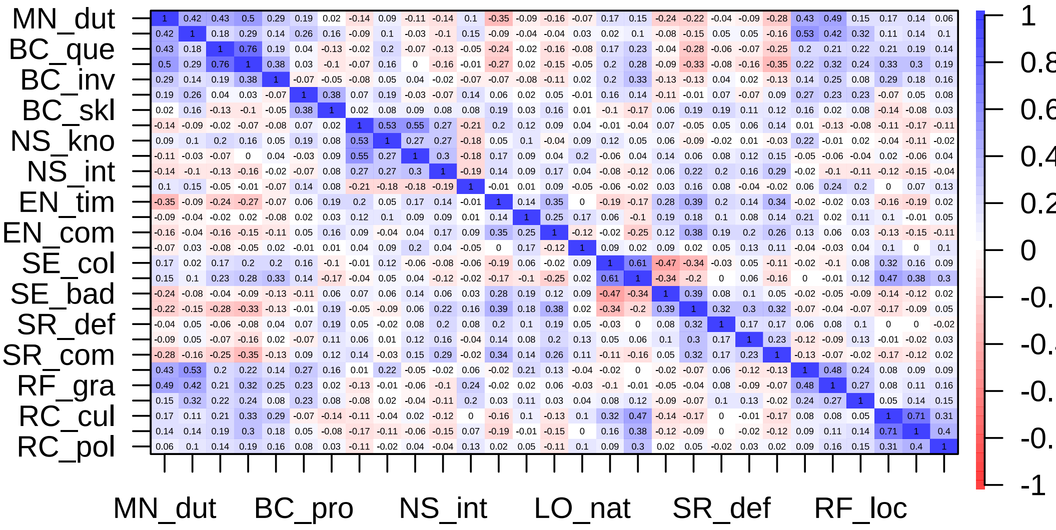
	PB_enj			PB_adv			PB_col			SB_kno			SB_opp			SB_dec		
	1	0.82	0.07	0.25	0.27	0.45	0.2	0.29	0.47	0.4	0.37	0.4	0.27	0.33	0.21	0.26	0.25	0.24
PB_sat	0.82	1	0.07	0.29	0.27	0.44	0.29	0.34	0.53	0.37	0.31	0.33	0.29	0.28	0.17	0.25	0.27	0.23
	0.07	0.07	1	0.4	0.29	0.04	0.29	0.22	0.11	0.17	0.16	0.12	0.17	0.22	0.36	0.36	0.15	0.16
PB_adv	0.25	0.29	0.4	1	0.5	0.32	0.44	0.43	0.33	0.03	0.16	0.1	0.09	0.18	0.27	0.19	0.18	0.26
	0.27	0.27	0.29	0.5	1	0.39	0.3	0.27	0.32	0.18	0.29	0.17	0.25	0.21	0.23	0.21	0.2	0.2
PB_exp	0.45	0.44	0.04	0.32	0.39	1	0.24	0.34	0.46	0.35	0.35	0.34	0.22	0.29	0.25	0.22	0.23	0.2
	0.2	0.29	0.29	0.44	0.3	0.24	1	0.62	0.38	0.18	0.25	0.14	0.13	0.24	0.24	0.23	0.34	0.37
PB_sha	0.29	0.34	0.22	0.43	0.27	0.34	0.62	1	0.52	0.15	0.32	0.17	0.19	0.25	0.22	0.26	0.32	0.36
	0.47	0.53	0.11	0.33	0.32	0.46	0.38	0.52	1	0.32	0.3	0.33	0.28	0.25	0.18	0.22	0.34	0.27
SB_kno	0.4	0.37	0.17	0.03	0.18	0.35	0.18	0.15	0.32	1	0.59	0.73	0.39	0.47	0.43	0.52	0.48	0.29
	0.37	0.31	0.16	0.16	0.29	0.35	0.25	0.32	0.3	0.59	1	0.47	0.28	0.32	0.39	0.53	0.61	0.49
SB_und	0.4	0.33	0.12	0.1	0.17	0.34	0.14	0.17	0.33	0.73	0.47	1	0.44	0.52	0.41	0.49	0.49	0.27
	0.27	0.29	0.17	0.09	0.25	0.22	0.13	0.19	0.28	0.39	0.28	0.44	1	0.44	0.48	0.39	0.33	0.29
SB_edu	0.33	0.28	0.22	0.18	0.21	0.29	0.24	0.25	0.25	0.47	0.32	0.52	0.44	1	0.44	0.44	0.41	0.25
	0.21	0.17	0.36	0.27	0.23	0.25	0.24	0.22	0.18	0.43	0.39	0.41	0.48	0.44	1	0.6	0.44	0.41
SB_dec	0.26	0.25	0.36	0.19	0.21	0.22	0.23	0.26	0.22	0.52	0.53	0.49	0.39	0.44	0.6	1	0.48	0.42
	0.25	0.27	0.15	0.18	0.2	0.23	0.34	0.32	0.34	0.48	0.61	0.49	0.33	0.41	0.44	0.48	1	0.48
SB_par	0.24	0.23	0.16	0.26	0.2	0.2	0.37	0.36	0.27	0.29	0.49	0.27	0.29	0.25	0.41	0.42	0.48	1

Figure C.2: Correlation plot for all variables associated with outreach benefits

Please see Table 4.13 for an explanation of the IDs.

Table C.3: Descriptive statistics for all variables associated with perceptions about outreach

id	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
MN_dut	1	391	4.25	0.95	5	4.40	0.00	1	5	4	-1.21	0.86	0.05
MN_tax	2	391	3.99	1.04	4	4.14	1.48	1	5	4	-1.00	0.56	0.05
BC_que	3	387	4.14	0.84	4	4.23	1.48	1	5	4	-0.86	0.54	0.04
BC_mat	4	387	4.16	0.93	4	4.29	1.48	1	5	4	-0.95	0.26	0.05
BC_inv	5	389	3.67	1.00	4	3.73	1.48	1	5	4	-0.35	-0.55	0.05
BC_pro	6	387	3.51	1.04	4	3.56	1.48	1	5	4	-0.43	-0.26	0.05
BC_skl	7	388	2.57	1.09	2	2.54	1.48	1	5	4	0.25	-0.76	0.06
NS_und	8	386	3.92	0.95	4	4.03	1.48	1	5	4	-0.69	-0.09	0.05
NS_kno	9	385	3.87	0.95	4	3.95	1.48	1	5	4	-0.63	0.09	0.05
NS_app	10	388	3.33	1.12	3	3.37	1.48	1	5	4	-0.27	-0.68	0.06
NS_int	11	389	2.81	1.14	3	2.79	1.48	1	5	4	0.16	-0.76	0.06
NS_sci	12	386	2.71	0.86	3	2.71	1.48	1	5	4	0.10	-0.12	0.04
EN_tim	13	388	2.57	0.95	3	2.56	1.48	1	5	4	0.25	-0.42	0.05
EN_mon	14	385	2.62	1.25	3	2.54	1.48	1	5	4	0.26	-0.92	0.06
EN_com	15	381	2.14	0.97	2	2.07	1.48	1	5	4	0.41	-0.61	0.05
LO_nat	16	391	2.24	1.42	2	2.05	1.48	1	5	4	0.75	-0.84	0.07
SE_col	17	389	3.83	1.02	4	3.93	1.48	1	5	4	-0.63	-0.03	0.05
SE_ins	18	389	3.88	1.04	4	4.01	1.48	1	5	4	-0.77	0.07	0.05
SE_bad	19	389	1.68	1.00	1	1.48	0.00	1	5	4	1.50	1.55	0.05
SE_ser	20	387	1.59	0.91	1	1.40	0.00	1	5	4	1.82	3.28	0.05
SR_def	21	389	2.63	1.09	3	2.62	1.48	1	5	4	0.07	-0.92	0.06
SR_sim	22	388	2.52	1.12	2	2.49	1.48	1	5	4	0.22	-0.88	0.06
SR_com	23	389	1.93	0.98	2	1.80	1.48	1	5	4	0.95	0.47	0.05
RF_sup	24	391	4.07	0.94	4	4.18	1.48	1	5	4	-0.96	0.70	0.05
RF_gra	25	391	3.17	1.23	3	3.21	1.48	1	5	4	-0.17	-0.96	0.06
RF_loc	26	385	3.34	1.08	3	3.34	1.48	1	5	4	-0.08	-0.72	0.05
RC_cul	27	391	3.18	1.11	3	3.19	1.48	1	5	4	-0.13	-0.72	0.06
RC_soc	28	391	2.98	1.02	3	2.98	1.48	1	5	4	0.04	-0.65	0.05
RC_pol	29	384	2.94	1.05	3	2.97	1.48	1	5	4	-0.06	-0.48	0.05



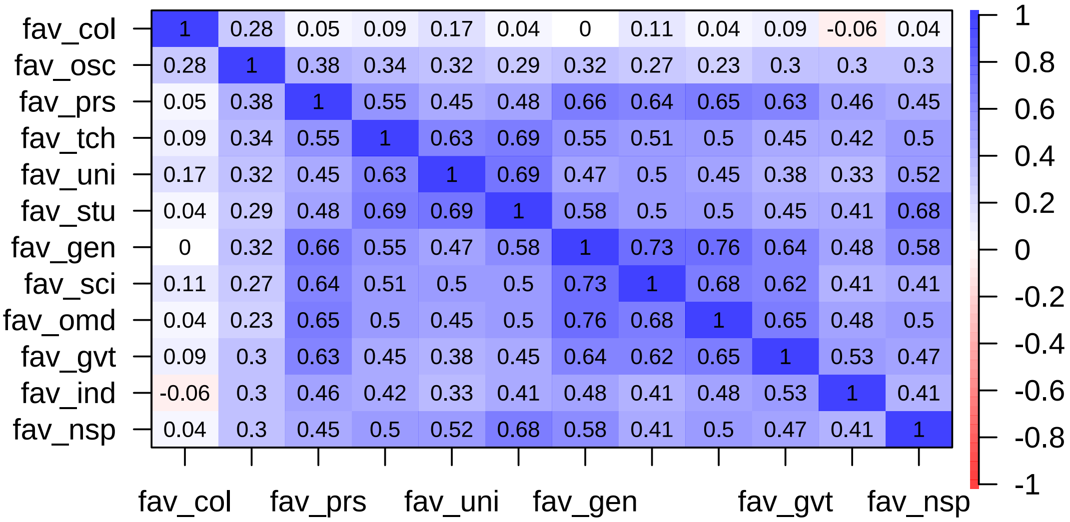
	MN_dut					BC_pro					NS_int					LO_nat					SR_def					RF_loc			
MN_dut	1	0.42	0.43	0.5	0.29	0.19	0.02	-0.14	0.09	-0.11	-0.14	0.1	-0.35	-0.09	-0.16	-0.07	0.17	0.15	-0.24	-0.22	-0.04	-0.09	-0.28	0.43	0.49	0.15	0.17	0.14	0.06
	0.42	1	0.18	0.29	0.14	0.26	0.16	-0.09	0.1	-0.03	-0.1	0.15	-0.09	-0.04	-0.04	0.03	0.02	0.1	-0.08	-0.15	0.05	0.05	-0.16	0.53	0.42	0.32	0.11	0.14	0.1
BC_que	0.43	0.18	1	0.76	0.19	0.04	-0.13	-0.02	0.2	-0.07	-0.13	-0.05	-0.24	-0.02	-0.16	-0.08	0.17	0.23	-0.04	-0.28	-0.06	-0.07	-0.25	0.2	0.21	0.22	0.21	0.19	0.14
	0.5	0.29	0.76	1	0.38	0.03	-0.1	-0.07	0.16	0	-0.16	-0.01	-0.27	0.02	-0.15	-0.05	0.2	0.28	-0.09	-0.33	-0.08	-0.16	-0.35	0.22	0.32	0.24	0.33	0.3	0.19
BC_inv	0.29	0.14	0.19	0.38	1	-0.07	-0.05	-0.08	0.05	0.04	-0.02	-0.07	-0.07	-0.08	-0.11	0.02	0.2	0.33	-0.13	-0.13	0.04	0.02	-0.13	0.14	0.25	0.08	0.29	0.18	0.16
	0.19	0.26	0.04	0.03	-0.07	1	0.38	0.07	0.19	-0.03	-0.07	0.14	0.06	0.02	0.05	-0.01	0.16	0.14	-0.11	-0.01	0.07	-0.07	0.09	0.27	0.23	0.23	-0.07	0.05	0.08
BC_skl	0.02	0.16	-0.13	-0.1	-0.05	0.38	1	0.02	0.08	0.09	0.08	0.08	0.19	0.03	0.16	0.01	-0.1	-0.17	0.06	0.19	0.19	0.11	0.12	0.16	0.02	0.08	-0.14	-0.08	0.03
	-0.14	-0.09	-0.02	-0.07	-0.08	0.07	0.02	1	0.53	0.55	0.27	-0.21	0.2	0.12	0.09	0.04	-0.01	-0.04	0.07	-0.05	0.05	0.06	0.14	0.01	-0.13	-0.08	-0.11	-0.17	-0.11
NS_kno	0.09	0.1	0.2	0.16	0.05	0.19	0.08	0.53	1	0.27	0.27	-0.18	0.05	0.1	-0.04	0.09	0.12	0.05	0.06	-0.09	-0.02	0.01	-0.03	0.22	-0.01	0.02	-0.04	-0.11	-0.02
	-0.11	-0.03	-0.07	0	0.04	-0.03	0.09	0.55	0.27	1	0.3	-0.18	0.17	0.09	0.04	0.2	-0.06	0.04	0.14	0.06	0.08	0.12	0.15	-0.05	-0.06	-0.04	0.02	-0.06	0.04
NS_int	-0.14	-0.1	-0.13	-0.16	-0.02	-0.07	0.08	0.27	0.27	0.3	1	-0.19	0.14	0.09	0.17	0.04	-0.08	-0.12	0.06	0.22	0.2	0.16	0.29	-0.02	-0.1	-0.11	-0.12	-0.15	-0.04
	0.1	0.15	-0.05	-0.01	-0.07	0.14	0.08	-0.21	-0.18	-0.18	-0.19	1	-0.01	0.01	0.09	-0.05	-0.06	-0.02	0.03	0.16	0.08	-0.04	-0.02	0.06	0.24	0.2	0	0.07	0.13
EN_tim	-0.35	-0.09	-0.24	-0.27	-0.07	0.06	0.19	0.2	0.05	0.17	0.14	-0.01	1	0.14	0.35	0	-0.19	-0.17	0.28	0.39	0.2	0.14	0.34	-0.02	-0.02	0.03	-0.16	-0.19	0.02
	-0.09	-0.04	-0.02	0.02	-0.08	0.02	0.03	0.12	0.1	0.09	0.09	0.01	0.14	1	0.25	0.17	0.06	-0.1	0.19	0.18	0.1	0.08	0.14	0.21	0.02	0.11	0.1	-0.01	0.05
EN_com	-0.16	-0.04	-0.16	-0.15	-0.11	0.05	0.16	0.09	-0.04	0.04	0.17	0.09	0.35	0.25	1	-0.12	-0.02	-0.25	0.12	0.38	0.19	0.2	0.26	0.13	0.06	0.03	-0.13	-0.15	-0.11
	-0.07	0.03	-0.08	-0.05	0.02	-0.01	0.01	0.04	0.09	0.2	0.04	-0.05	0	0.17	-0.12	1	0.09	0.02	0.09	0.02	0.05	0.13	0.11	-0.04	-0.03	0.04	0.1	0	0.1
SE_col	0.17	0.02	0.17	0.2	0.2	0.16	-0.1	-0.01	0.12	-0.06	-0.08	-0.06	-0.19	0.06	-0.02	0.09	1	0.61	-0.47	-0.34	-0.03	0.05	-0.11	-0.02	-0.1	0.08	0.32	0.16	0.09
	0.15	0.1	0.23	0.28	0.33	0.14	-0.17	-0.04	0.05	0.04	-0.12	-0.02	-0.17	-0.1	-0.25	0.02	0.61	1	-0.34	-0.2	0	0.06	-0.16	0	-0.01	0.12	0.47	0.38	0.3
SE_bad	-0.24	-0.08	-0.04	-0.09	-0.13	-0.11	0.06	0.07	0.06	0.14	0.06	0.03	0.28	0.19	0.12	0.09	-0.47	-0.34	1	0.39	0.08	0.1	0.05	-0.02	-0.05	-0.09	-0.14	-0.12	0.02
	-0.22	-0.15	-0.28	-0.33	-0.13	-0.01	0.19	-0.05	-0.09	0.06	0.22	0.16	0.39	0.18	0.38	0.02	-0.34	-0.2	0.39	1	0.32	0.3	0.32	-0.07	-0.04	-0.07	-0.17	-0.09	0.05
SR_def	-0.04	0.05	-0.06	-0.08	0.04	0.07	0.19	0.05	-0.02	0.08	0.2	0.08	0.2	0.1	0.19	0.05	-0.03	0	0.08	0.32	1	0.17	0.17	0.06	0.08	0.1	0	0	-0.02
	-0.09	0.05	-0.07	-0.16	0.02	-0.07	0.11	0.06	0.01	0.12	0.16	-0.04	0.14	0.08	0.2	0.13	0.05	0.06	0.1	0.3	0.17	1	0.23	-0.12	-0.09	0.13	-0.01	-0.02	0.03
SR_com	-0.28	-0.16	-0.25	-0.35	-0.13	0.09	0.12	0.14	-0.03	0.15	0.29	-0.02	0.34	0.14	0.26	0.11	-0.11	-0.16	0.05	0.32	0.17	0.23	1	-0.13	-0.07	-0.02	-0.17	-0.12	0.02
	0.43	0.53	0.2	0.22	0.14	0.27	0.16	0.01	0.22	-0.05	-0.02	0.06	-0.02	0.21	0.13	-0.04	-0.02	0	-0.02	-0.07	0.06	-0.12	-0.13	1	0.48	0.24	0.08	0.09	0.09
RF_gra	0.49	0.42	0.21	0.32	0.25	0.23	0.02	-0.13	-0.01	-0.06	-0.1	0.24	-0.02	0.02	0.06	-0.03	-0.1	-0.01	-0.05	-0.04	0.08	-0.09	-0.07	0.48	1	0.27	0.08	0.11	0.16
	0.15	0.32	0.22	0.24	0.08	0.23	0.08	-0.08	0.02	-0.04	-0.11	0.2	0.03	0.11	0.03	0.04	0.08	0.12	-0.09	-0.07	0.1	0.13	-0.02	0.24	0.27	1	0.05	0.14	0.15
RC_cul	0.17	0.11	0.21	0.33	0.29	-0.07	-0.14	-0.11	-0.04	0.02	-0.12	0	-0.16	0.1	-0.13	0.1	0.32	0.47	-0.14	-0.17	0	-0.01	-0.17	0.08	0.08	0.05	1	0.71	0.31
	0.14	0.14	0.19	0.3	0.18	0.05	-0.08	-0.17	-0.11	-0.06	-0.15	0.07	-0.19	-0.01	-0.15	0	0.16	0.38	-0.12	-0.09	0	-0.02	-0.12	0.09	0.11	0.14	0.71	1	0.4
RC_pol	0.06	0.1	0.14	0.19	0.16	0.08	0.03	-0.11	-0.02	0.04	-0.04	0.13	0.02	0.05	-0.11	0.1	0.09	0.3	0.02	0.05	-0.02	0.03	0.02	0.09	0.16	0.15	0.31	0.4	1

Figure C.3: Correlation plot for all variables associated with perceptions about outreach

Please see Table 4.17 for an explanation of the IDs.

Table C.4: Descriptive statistics for all variables associated with the audience groups

id	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
fav_col	1	391	14.04	1.39	15	14.34	0.00	9	15	6	-1.82	2.95	0.07
fav_osc	2	391	11.07	1.88	11	11.16	1.48	4	15	11	-0.52	0.36	0.10
fav_prs	3	391	8.65	2.94	9	8.75	2.97	2	15	13	-0.26	-0.67	0.15
fav_tch	4	391	9.75	2.41	10	9.88	2.97	2	15	13	-0.54	0.16	0.12
fav_uni	5	391	10.92	2.10	11	11.03	1.48	4	15	11	-0.59	0.28	0.11
fav_stu	6	391	8.89	2.54	9	9.00	2.97	2	14	12	-0.35	-0.39	0.13
fav_gen	7	391	7.12	2.60	7	7.11	2.97	2	14	12	0.02	-0.55	0.13
fav_sci	8	391	9.82	2.76	10	10.04	2.97	2	15	13	-0.64	-0.11	0.14
fav_omd	9	391	7.53	2.71	8	7.57	2.97	2	14	12	-0.07	-0.61	0.14
fav_gvt	10	391	7.81	2.64	8	7.85	2.97	2	14	12	-0.11	-0.48	0.13
fav_ind	11	391	7.42	2.75	7	7.39	2.97	2	14	12	0.09	-0.78	0.14
fav_nsp	12	391	8.24	2.56	8	8.27	2.97	2	14	12	-0.11	-0.57	0.13



	fav_col		fav_prs		fav_uni		fav_gen			fav_gvt		fav_nsp
fav_col	1	0.28	0.05	0.09	0.17	0.04	0	0.11	0.04	0.09	-0.06	0.04
fav_osc	0.28	1	0.38	0.34	0.32	0.29	0.32	0.27	0.23	0.3	0.3	0.3
fav_prs	0.05	0.38	1	0.55	0.45	0.48	0.66	0.64	0.65	0.63	0.46	0.45
fav_tch	0.09	0.34	0.55	1	0.63	0.69	0.55	0.51	0.5	0.45	0.42	0.5
fav_uni	0.17	0.32	0.45	0.63	1	0.69	0.47	0.5	0.45	0.38	0.33	0.52
fav_stu	0.04	0.29	0.48	0.69	0.69	1	0.58	0.5	0.5	0.45	0.41	0.68
fav_gen	0	0.32	0.66	0.55	0.47	0.58	1	0.73	0.76	0.64	0.48	0.58
fav_sci	0.11	0.27	0.64	0.51	0.5	0.5	0.73	1	0.68	0.62	0.41	0.41
fav_omd	0.04	0.23	0.65	0.5	0.45	0.5	0.76	0.68	1	0.65	0.48	0.5
fav_gvt	0.09	0.3	0.63	0.45	0.38	0.45	0.64	0.62	0.65	1	0.53	0.47
fav_ind	-0.06	0.3	0.46	0.42	0.33	0.41	0.48	0.41	0.48	0.53	1	0.41
fav_nsp	0.04	0.3	0.45	0.5	0.52	0.68	0.58	0.41	0.5	0.47	0.41	1

Figure C.4: Correlation plots for all variables associated with the audience groups