# The Lowest Common Denominator?

A Newcastle Case Study on Research Practice and Disciplinarity in Nanoscale Science and Technology.

Matthias Wienroth

A thesis submitted for the degree of Doctor of Philosophy
in the School of Geography, Politics and Sociology
at the University of Newcastle upon Tyne.

September 2008.

*Für meine Eltern*

*und meine Doktoreltern*

# Abstract

My PhD thesis explores the nature of Nanoscale Science and Technology, in particular how this new and emergent research field is constructed in science practice. I examine the socio-technological worlds of scientists in NST, in particular their disciplinary identity construction, and their negotiation of NST as a research field. I identify three dimensions of identity here: belonging, practice, and strategy. Scientists negotiate their structural belonging; their actual crossdisciplinary research practice; and the potential research areas they can work in as a strategic element of research accountability and career planning. Crossdisciplinary research collaboration is a dominant aspect of research in NST, and as such in the socio-technological worlds of scientists. My analysis suggests how collaboration emerges, and what its defining aspects are. This connects to the role of disciplinarity and epistemology in collaboration: crossdisciplinarity and problem-orientation in NST research have considerable impact on scientists' identity negotiation. Both identity and collaboration feature in the boundary work of academic scientists towards non-academic and non-scientific elements in NST research.

The main findings of my research suggest that NST is negotiated in contrasting narratives, and in crossdisciplinary research collaboration. The nature of NST can be described as (1) dichotomous as it is constructed through social and scientific debates. This dichotomy renders demarcation for scientists necessary to distinguish between 'real' science and science fiction, and to uphold the notion of factual scientific knowledge in academic science and thus account for funding such research. At the same time, this dichotomy helps to explain the 'critical distancing' that scientists narrate in regard to NST as a legitimate field of scientific endeavour. I propose that NST is also (2) a transdisciplinary meta-structure, based on various disciplines' input, but at the same time feeding back knowledge into the established disciplinary structure. This meta-structure requires scientists to diversify their disciplinary identity in disciplinary boundary work. The third finding of my research suggests that (3) NST is a socio-technoscience, where basic and advanced knowledge production is conducted with a view to technology production and its application in society. Combined with contemporary currents in science governance, this is advanced by increased accountability of research. In turn, this advances increased boundary work of scientists by distinguishing academic-scientific knowledge production from non-academic and non-scientific aspects of knowledge production in society. Here, the notion of 'pure' science as neutral and societal interest-free is promoted by scientists to distinguish academic research from other forms of science.

# Acknowledgements


“I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I –
I took the one less travelled by,
And that has made all the difference.”
*Robert Frost*

Without the support of my family and friends back home, and of new friends and colleagues here in Newcastle, the road I have travelled for the past three years would have been difficult. When I decided to apply for, and was offered, a PEALS doctoral studentship, I decided against a career in journalism, a path I was more familiar with through years of freelance work. And I decided to leave Germany and live in the UK. However, the experiences I have shared with friends and colleagues on this road so far have been rich and rewarding, kindling the urge to press on.

There are a number of people, who have been my guides and foothold during the past three years. To my family I am always grateful for their emotional and financial support, without which I would never have been able to come to Newcastle, and to stay on. To my supervisors, Erica Haimes and Simon Woods, I am deeply indebted for their intellectual support, their openness and encouragement. To my friends I give thanks for being there in times of need, and for making this route a fuller experience. And to the people at PEALS I am grateful for their warm welcome in Newcastle, and for being an encouraging and supportive environment, both as colleagues and as friends.

I am very grateful to the Policy, Ethics and Life Science Research Centre, The School of Geography, Politics and Sociology, and Newcastle University for their financial support. I would also like to thank The European Network of Excellence 'Nano-2-Life' and its participants for allowing me to travel to talks and events with them, and for helping me in making a picture for myself of activities in the field of Nanoscale Science and Technology.

Last, but not least, I thank all the academic scientists in the North-East of England, who have participated in my research, for their time, information and trust.

# List of Contents

# List of Tables and Figures

**Tables**



**Figures**

# Chapter 1: New Knowledge, New Academia?



## 1 Introduction

This study is about Nanoscale Science and Technology (NST). It is about a new and emergent field of science and technology and the impacts of that field on academic science. It explores how aspects of that field permeate and even change academic knowledge and technology production. Overall, this research contributes to the analysis of contemporary science practice in academia.

I first encountered nanotechnology in science-fictional narratives (TV programmes and graphic novels). The idea of being able to affect the material world from some of its smallest elements up, has impressed itself on my view of science generally. Pushing the boundaries and attempting to exert more control over the world around us is what knowledge production in science seems to be about. However, it has been specific and sometimes outrageous examples, like the concept of 'nanobots' (molecule-sized artificial machines) or of cloning, that have had the most impact in generating interest, or even enthusiasm, in me for exploring how science works and how technologies are developed. Nanobots, as unlikely as they might be in scientific terms, stimulated my interest in exploring NST.

Doing research at the nanoscale, at the scale of atoms and molecules, requires immense scientific effort and a vast amount of intellectual energy. It also brings together very diverse scientific disciplines and research fields, collaborating to produce knowledge and technology.

NST impacts, however, are to be expected not only for the way knowledge is produced but also on society, especially its reception and application by various stakeholders and users. This opens up a wide range of questions as to the nature of NST, what it can do and what it sets out to do. For example: are understandings of NST consistent? How is knowledge produced coherently when it is a precondition that disciplinary boundaries need to be crossed (and thus different epistemologies interact)? What impacts does this have on science organisation and researchers' understanding of their research-self?

To claim an understanding of a research field involves coming to terms with its potential and the aspects that influence it. For this, it helps to understand the mechanisms and elements of how science is conducted, of how understandings of, and knowledge in, a field are produced (see such different science practice studies by Fleck, 1980; Kuhn, 1993; Latour and Woolgar, 1986). Therefore, in my study overall I aim to construct an understanding of how NST is negotiated by researchers. An important element to include is the practice-orientated perspectives of academic scientists in the debate around contemporary academic science. Herein, also, lies the origin of the title of this thesis, which functions at the same time as the overarching question of this study. '*The lowest common denominator*' refers to the links that render NST the coherent entity that is debated in such lively terms in science, science policy and social studies of science. This implies also an enquiry into how and why these links are established. I aim to explore these questions by examining processes and mechanisms within the practices of NST.

The focus here is on disciplinarity and aspects of identity and collaboration. Disciplinarity is an important structuring element in academic science. Science is organised based on epistemologies, which provide the core of diverse disciplines. Through identification processes and scientists' positioning towards NST the field's disciplinarity can be explored, in regard to established disciplinary structures especially. Collaboration is an element that becomes increasingly significant in science practice, and leads to transgressing disciplinary boundaries. All of the three main themes of this thesis, therefore, can provide the basis for an understanding of NST as a new and emergent field of science and technology in academic science. I provide a more elaborate overview of each of the themes later in this chapter.

I refer to 'Nanoscale Science and Technology' throughout this thesis as a central concept in the 'network' of concepts in nanoscale research. It loosely combines the aspects of science, technology and their relation to the nanoscale. In NST, basic science directed at the scale of atoms and molecules is applied to problems of the 'real world', that is to challenges of technologies in the macro-world of society. A transfer needs to take place from the protected space of the laboratory to the application of scientific knowledge and technology in society. NST is an entity in which this transfer is expected to take place. In chapter 2 I discuss the concept of 'technoscience' in more depth, which provides the theoretical framework for my use of NST.

Because scientific development in NST is still in its infancy, it provides a very useful arena for exploring how a science and technology field emerges and impacts on existing structures, both in science and society. Genomics, systems and synthetic biology, and nanotechnology are all topical research fields where knowledge, methods and tools of different sciences need to contribute to produce knowledge and technologies, where the boundaries between disciplinary expertise overlap and need to be overcome. I have chosen to focus on NST because it has been described as having an especially enabling and disruptive potential. 'Enabling' in the way that nanotechnologies can provide access to the nano-realm, and beyond, through further research, bringing together the physical, chemical and biological aspects of the material world with engineering skills of humanity; 'disruptive' because nanotechnologies bear the potential to change the contemporary social world dramatically. These claims, which I portray in more detail in the next chapter, imply an understanding of the material world that goes beyond disciplinary confines and, I believe and argue in my analysis of researchers' perceptions, require synergies between disciplines and sub-disciplines of various and diverse expertise. At the same time, the attributed disruptive nature – by lobbying scientists, social scientists and politicians – makes NST a field of particular societal interest and social investigation. NST is also a productive field to study as the aspiration of NST is at once both reductionist and holistic. It is reductionist because of the focus on atoms and molecules and their control. It is holistic because nanoscale research draws from diverse scientific expertise, and research in this field requires knowledge to become compatible and transferable across disciplinary boundaries. Nanotechnologies have the potential to change not only inanimate matter, but the stuff of life itself.

# Chapter 1: New Knowledge, New Academia?

My aim is to explore changes taking place in research practice and structure. In particular, I am interested in these changes in the context of the *scientific* study of increasingly fundamental – smaller in scale and stranger in nature – elements, structures and processes of the material world. In NST, it is the strange world of quantum mechanics, whose understanding and control might considerably change the way the world can be understood and influenced. Moving between the nanoscale and the world we can see, touch and feel is an immense transgression of spaces and scale, but also of physical laws. It is appropriate, then, to take NST as an example of exploring processes and structures of transgressing knowledge and practices (cf. Bogner, 2005; Nowotny *et al*, 2001) and hybridisation (cf. Haraway, 1997; Latour, 2000) in knowledge production in science and technology.

In research, the scientific and social dimensions are closely entwined. Researchers need to collaborate due to the growing complexity of research problems encompassing diverse kinds of disciplinary expertise. At the same time, the 'social' features in accountability mechanisms of science practice (Strathern, 2004:68ff) where research needs to be legitimised and produce socially robust, compatible and utilisable knowledge and technology. These transgressions of the 'social' and the 'scientific' have been described in terms of 'co-evolution' (cf. Rip, 2002, 2005) and 'co-production' (Jasanoff, 2006) of science and society. For science, the concepts of co-evolution and co-production describe the transgression and diffusion of disciplinary boundaries and thus the changing structure and practice in academic science. For science in society, co-evolution and co-production refer to the changing structure and practice, to knowledge production taking place in society, and the diverse scientific and social influences on science.

A thorough understanding of how science in NST is practised is one of the first steps to understanding how NST can be governed and how the societal element can be drawn out in the interplay between scientific and social aspects of nanoscale research. At the same time, the strong emphasis of 'interdisciplinarity' and 'transdisciplinarity' in nanoscale research calls for research into the apparently changing nature of academic science.

## 2 New Knowledge, New Academia?

NST is an example of transgression and hybridisation processes in new and emergent science and technology (NEST) fields. Social research into NST has so far concentrated on institutions, public engagement analysis, science policy, lobbying scientists – more politicians than laboratory-based researchers – and on scientific interaction in journals. Existing social research produces a picture of NST, or generally of new and emergent science and technologies, that does not do justice to the polychromatic understandings of contemporary science processes. There are only a few studies that go beyond the outer shell, go beyond including scientists from afar through the looking glass of non-scientific activity. A number of studies refer to science practice by looking at scientific interaction and presentations of NST in academic journals (cf. Bueno, 2004b; Schummer, 2004b; for an earlier overview see Hullmann and Meyer, 2003). However, this approach also rests too much on the external interpretation of the (often non-scientist) analyst and leaves out scientists' views and experiences altogether. Even when scientist-cum-social scientists look at science, there seems to be a missing link to practising scientists who are not in the science policy limelight. Indeed, there are only a handful of studies penetrating the space where research takes place. These few studies look at how the scientific and social elements of the above mentioned transgression and hybridisation processes affect knowledge production (see for example Doubleday, 2007a; Johansson, 2008). My study takes a similar path by exploring the structure and practice of NST through scientists' perception of collaboration and NST as featuring in their research interests. It is this aspect of how contemporary, crossdisciplinary research collaboration in a new and fast-developing field is perceived by scientists themselves that is the novel element in my study. Combined with structural and practical disciplinary, and research identity aspects, I believe my study contributes to understanding how contemporary science is practised and, through those practices, is developed and changed.

My research is part of a recent move of researchers towards including scientists' perspectives into the analysis of NST. Exploring contemporary science, its mechanisms and agencies helps to render the social study of knowledge production more robust, especially as NST and other emerging crossdisciplinary research fields present challenges to disciplinarity and knowledge production, both in structure and practice. This is a compelling reason for the pursuit of understanding and the production of knowledge in the context of the Sociologies of Science and Technology (SST) and of Scientific Knowledge (SSK).

The enquiry into scientists' perception of NST, furthermore, presents a contribution to Science and Technology Studies (STS) as a practice-orientated field in the context of the changing role of academic science in society. There are, I believe, three dimensions to the reasoning for my study, which I conceptualise here as the science-individual, the socio-scientific, and the ethico-sociological. The *science-individual* dimension refers to the role and position of scientists in society, whereas the *socio-scientific* refers to the structural and practice-based change of academic knowledge production. The *ethico-sociological* dimension regards the input that social science can provide for the understanding of practice and thus ethical considerations.

*The Science-Individual Dimension*

The individual scientist's perception does not often feature in analytical accounts of NST. This may be because their position is considered to be well known and they are thought to be well established in society. This attitude, however, can help to distort and misrepresent the role of scientists by simplifying their views, but also by summarising scientists' views into one perspective.

At the same time, the role and esteem of academic scientists has been changing, due to modified societal expectations and requirements of academic science, but also due to the changing nature of scientific problems, opportunities and limitations. The academic scientist is still a teacher and researcher, but there are now increasing requirements placed on research institutions, and thus researchers, to account for research practice and the trajectories of knowledge production. I discuss the context of this in more detail further below. For the academic scientist this can mean a changed understanding of academia's role and scientific freedom. In the wake of increasing science-public engagement an image of the scientist has emerged that shows the researcher as someone who needs to come to terms with diverse publics' understandings of science and technology as much as those publics need to come to terms with the science and technologies (as indicated in public engagement undertaken, see for example Gavelin *et al*, 2007 and Stilgoe, 2007). At the same time, academic scientists remain primarily researchers. My research contributes to the exploration of how they understand NST and the crossdisciplinary (encompassing at least multi- and interdisciplinarity) collaborative element that seems so vital to contemporary science.

*The Socio-Scientific Dimension*

The role of academic science in society has been described in the context of the 'knowledge society' (Nowotny *et al*, 2001) in which science and society mutually influence one another in co-evolution but retain their distinct trajectories. Nowotny *et al* refer to the 'agora' as the market place for interaction between scientists and the 'educated' (2001:203ff), where discourses and negotiations in regard to scientific knowledge and technology take place. Knowledge here is co-produced in that technologies are socially influenced (cf. Williams and Edge, 1996) by the researchers themselves, for example in the choice of scientific rationalisation of technological development (cf. Van den Belt and Rip, 1987), and from the outside of the research laboratory, for example in funding and science policies, and also in the requirements of industry and commerce. This 'social deterministic' approach, that is the strong influence ascribed to social elements in science, is the vantage point for any up- or midstream modulation (change) programme for science and technology, both in public engagement and in science planning.

At the same time, knowledge and technology play a significant role in the production of new knowledge and technology. They provide frameworks and tools to how and what knowledge or technology can be produced, or even how knowledge can be interpreted. In the case of nanotechnology this refers to the ability to imagine what is going on at the scale of atoms, and to exert any kind of structuring or controlling influence on atoms and molecules. The dominant focus on this technical contribution can be referred to as 'technological determinism' of knowledge production.

However, both notions interact and influence how knowledge and technology are produced. Therefore, the term 'determinism' is rendered obsolete. The co-evolutionary model of science and society interaction in knowledge and technology production circumvents deterministic thinking because it attributes both dimensions, the social and the scientific, equally influential roles (cf. Rip, 2002, 2005).

Instead, the idea of 'Mode 2' is taken further in this theoretical context. 'Mode 2' broadly conceptualises collaborative research taking place in academia under the increasing influence of societal interests (see 'knowledge society' above). I refer to 'Mode 2' in this thesis to emphasise the collaborative nature of scientific research, its changing disciplinary nature, and the interconnectivity between scientific and societal aspects in academic research. Thus, I adapt the idea of 'Mode 2' for my analysis. A model drawing from the strong societal impact on science is the 'triple helix'. Etzkowitz and Leydesdorff (2000) conceptualise it as an interactive model of academia, commerce and government. The 'triple helix' encompasses institutional issues of science policy and science economics, the interconnectivity of those three spheres in the co-production of knowledge. In chapter 2, I further discuss these concepts and their connections in regard to NST.

Academic science is part of a wide network of institutional scripts, motivations, interests and expectations, promises and requirements, contributions and demands; and it is all of that in itself. A current example of this interactivity in science policy is the debate around science as a public good. The physicist Philip Moriarty takes up the case of 'non-instrumental' science (2008) to criticise and resist further tendencies to a commercialisation of academic science. Science, he argues, is an endeavour in itself and inherently for society, and is thus a public good requiring public funding, to protect academic science from the need to commit to commercial agendas and thus to business interests. This provides an example of the reach of the 'triple helix' whilst simultaneously emphasising that the notion of *pure science*, as knowledge production that is free of non-scientific interest, remains strong in academic science. I consider 'pure' science in chapters 6 and 7.

Examining the self-perception of academic scientists, and their understanding of their research, can further the understanding of how science and society interact.

*The Ethico-Sociological Dimension*

The third dimension of reasoning refers to the epistemological outlook of social science in the context of ELSA (ethical, legal and social aspects) studies in new and emergent research fields such as nanotechnology, biotechnology, information technology and cognitive science. Debates and research on NST and other emergent fields, especially in the so-called converging science and technology fields constituted by research areas such as the above, often include the exploration of non-technological aspects in a science-political attempt to create “socially robust science” (Strathern, 2004:88). ELSA studies represent one area contributing to practised co-production, another is the broad area of public engagement in exploring the public's role and take on science and NST. Often, the ethical and the legal aspects seem to prevail in such considerations, next to the economic one. The area of *bioethics* provides one such example.

However, sociology and the social sciences in general can and need to contribute to ELSA. Therefore, my study contributes to “mak[ing] the voice of the social sciences heard more clearly” in ELSA (Haimes, 2002:91) by focussing on social activity (collaboration) and agency (identity) within science and the social element between science and society. This element is constituted by perceptions of all stakeholders in specific research fields, such as scientists, universities, governmental and non-governmental interest groups, industry and commerce, and the public as a diverse group. Scientists' perspectives on non-academic collaboration and their views on non-scientific aspects in their research can help prepare the path for improved communication and co-production. Research practices and trends of conduct directly connect to the ethics of doing science and producing knowledge (cf. Haimes, 2002:95), as do the mechanisms of accountability in science. Exploring and understanding these can help develop mechanisms and processes to produce socially robust science.

## 3 Structure and Practice

To address these three dimensions and contribute to the debate around science's role in society, I have chosen the case of NST. As it is depicted in the literature as a novel and emerging research field by social and physical scientists alike, I believe it works well as a basis for observing modifications in the practice and structure of academic science. A study of nanoscale researchers' views on collaboration can help to understand how the negotiation of new science and technology fields takes place and how these are defined and reproduced in aspects of research identity affected by adapting disciplinarities. However, to open up this 'black box' a number of subsidiary questions need to be addressed.

- How do scientists, working at the nanoscale, perceive NST?
- What role does NST play in scientists' construction of their research identity?
- Does disciplinarity still feature in the construction of research identity? If so, how?
- What role does crossdisciplinary collaboration play for research in the field of NST?
- What kinds of disciplinarity feature in NST-collaboration?
- Is NST becoming a discipline in its own right?
- How do scientists perceive their research in regard to its uptake in society?

These questions revolve around three main themes, which act as guidelines in my analysis: (1) crossdisciplinary collaboration, (2) research identity; and (3) structural and practice disciplinarity. I started out with the theme of collaboration. During my literature analysis, the aspect of disciplinarity in collaboration emerged, which has also influenced the theme of structural disciplinarity. In the analysis of my fieldwork, research identity emerged as another main pillar of understand research practice, which lead to the discussion of structural and practice disciplinarity.

As becomes apparent in the following chapters, especially in chapters 4 to 7, these three themes are very closely interlinked so that it would make little sense to look at one of these alone or entirely separated from the others. Instead, the division into three themes constitutes the scaffolding to explore scientists' perceptions of their research practice in NST.

*Disciplinarity*

The nature of disciplinarity is twofold: structural and practical. The disciplinary structure refers to the organisation and institutionalisation of academia and science generally, to disciplines and subdisciplines, their epistemologies, models, methodologies and methods. In the university, the structural division of science into specific disciplines is very strong, with many sub-disciplinary entities offering a home to specialised expertise, expertise that often looks beyond the strict epistemological and methodological boundaries of a discipline whilst remaining in their respective disciplines.

Since the early twentieth century, with the establishment of Big Science (Esparza and Yamada, 2007; Rip, 2000) and what Woolgar refers to as 'the professional turn' in science

(1988:19f), the boundaries of many disciplines have shifted and new disciplines have emerged in academia. This is due to the disciplinary practice that reacts to new problems and novel opportunities, but has also to do with the notion of self-preservation of the academy in society in reaction to the increasing amount of science conducted in industry. Science's main practitioners (professional industrial, and later also academic scientists) have realised the advantages of collaborating with specialists of different, complementary or enabling expertise (cf. Katz, 1996). Crossdisciplinary collaboration seems a keystone in stretching the boundaries of science further to explore and influence the world in novel and wider-reaching ways.

With the emergence of such varied research fields such as Life Sciences and biotechnology, and NST, which encompass vast knowledge and skills, the disciplinary structure in science, but also in academia in general, is on the verge of changing fundamentally. Administrative entities such as research institutes, degree programmes and professorial chairs adopt outlooks (and denominations) that focus on biotechnology or nanotechnology, that is on applied science and on technology production spanning diverse expertise from very different disciplinary backgrounds. Here, the disciplinary practice, in both individual research specialisation and in collaboration, takes a lead role in defining research, especially the crossdisciplinary kind that transgresses disciplinary boundaries and thus paints a rather different picture in comparison to the administrative layout of academic science. Crossdisciplinarity hereby encompasses different types of disciplinary practice: multi- and interdisciplinarity being the most often occurring in the literature. I explore the three key practice disciplinarities in the next chapter.

*Crossdisciplinary Collaboration*

Collaboration "is generally treated as meaning the cooperative way that two or more entities work together towards a shared goal" (Frey *et al*, 2006:384). It takes place on different levels and in diverse forms, ranging from networking and coordinating to full-scale collaboration and can lead to institutionalisations of such collaboration (Corley *et al*, 2006:976), ranging from an informal network to an established institution. By what means, however, is the 'shared goal' constituted? Collaboration rests on many different motivations. Wagner and Leydesdorff contend that personal interests of researchers are the main reasons (more so than structural, institutional or policy factors) for a steady growth of international collaborations in science, emphasised by a general notion of competition and supported by strong international networks (2005:1616). However, I believe the structural settings of research, its institutional scripts and science policies form the tableau for the motivation of collaboration, both on national and international scale. I believe that the science structure regarding scientific content, research problems and available approaches, in particular, plays a significant role in forming researchers' motivations to enter into collaboration, especially crossdisciplinary collaboration. For the case of knowledge production in NST the notion of collaboration becomes paramount.

Crossdisciplinary collaboration in science describes working together on projects or providing support of any kind to colleagues with different disciplinary backgrounds. It can take place at any of the above levels, but increases in potency through epistemologically and personally growing collaborative closeness. In my study, the 'cross-' in crossdisciplinarity is an abbreviation for all kinds of collaboration that include specialisations from different disciplinary expertise, whether this be *among* (multidisciplinary) or *across* (interdisciplinary) disciplines. There are further first order disciplinarities conceptualising different means of disciplinary collaboration. However, I focus on the two above, and *transdisciplinarity* as the third central concept, in my analysis because these concepts describe the epistemic impacts that collaboration can have on disciplinarity that are of interest to my analysis of knowledge production. Also, these are the main concepts used in the social science debate and, as such, more or less well-known, if not definitively established.

*Research Identity*

In the context of disciplinarity and collaboration, research identity refers to a scientist's sense of self and place within the disciplinary structure of science and, in particular, in crossdisciplinary research practice (cf. Ponterotto and Grieger, 1999:52). This self-perception is partly expressed in demarcation mechanisms that are an element of the on-going identification process. These mechanisms help to establish boundaries (cf. Simmel, 2007) for the scientist to be part of a group, whilst at the same time, distinguishing him- or herself from that group of shared epistemic culture or institutional structure and so forth. Identity can emerge through a variety of mechanisms. In my research, intersubjectivity in identification processes (cf. Williams, 2000:80-100) is of greatest interest. In attempting to understand scientists' perception of structure and practice in NST, and thus how NST is constructed, researchers' narratives of their research practice and of their understanding of NST, as well as their interactional reflection on collaboration, seem the most prudent to pursue.

*Scripts and Narratives*

Researchers' identities are negotiated through narratives; they connect to and make use of narratives whilst contributing to these. As such, narratives are reflexive, particularly in retrospect. Narratives can provide a context to decisions and actions; they represent a certain understanding and thus provide a rationale for following certain scripts. Scripts describe generic ways of acting and reacting in specific circumstances, comparable to institutional routines (cf. Łojek-Osiejuk, 1996:58). In my analysis, I use the concept of scripts as routines that are adopted by scientists in science practices of emerging NST due to experiences of success connected to following these. This also implies an interactional element to the adherence to scripts in the context of narratives (compare with Andrew and McMullen, 2000), helping to consolidate institutionalisation through learning, and by attributing certain elements, such as advantages. Thus, the concept is closely connected to practical reasoning and imitation (DiMaggio and Powell, 1991:26f). Scripts emerge from narratives, whilst contributing to these. Whereas narratives are internalised, scripts can often remain external. In the case of NST, the conceptualisation of 'nano' may be criticised by many of my respondents. They nevertheless tend to adhere to certain scripts of NST by taking advantage of elements as described in chapter 4.

## 4 Overview of This Thesis

The last section of this introductory chapter is devoted to a brief overview of the chapters to come.

The second chapter furthers the fundamental groundwork for my analysis, which I commenced here with introductions to the key themes. It constitutes a literature review of the social and scientific debates around NST as much as it provides the framework for my analysis and is therefore a formal account of the field and its analysis. I begin with a concise and science-focused overview of the history of NST followed by a discussion of key concepts and terms of NST to support the subsequent exploration of two main scientific narratives in NST about its origin. Contributing to the ongoing NST-narratives are diverse stakeholders in science, social science and humanities, commerce and politics. Therefore, I add as a third narrative strand the area of risk and technology assessment in NST, followed by a brief reflection on the state of the recent educational institutionalisation of NST. Lastly, I provide a short introduction to the role of disciplinary practice in NST as this is one of the foci of my study.

The third chapter is devoted to the methodological orientation of my research. I aim to provide a short history of my project by considering the epistemological background of this study, the methodological choices I made, and the general development of my study. I aim to narrate the emergence of ideas, choices and issues, and provide an account of my deliberations during the research process. Thus, I discuss the epistemic background to my particular study, which I elaborate with an account of my motivations, and the advantages and drawbacks of conducting a case study of NST in the North-East of England. I then reflect on the choice of research methods, on my fieldwork experiences, on ethical issues and on the analysis process.

The following four chapters focus on my analysis of the research field of NST. In chapters 4, 5 and 6 I present my analysis according to guiding key themes, whilst in chapter 7 I draw these strands together to evaluate their overall contribution. I then look forward as to where my research might lead in the future.

Chapter 4 provides an analysis of the socio-technological worlds of academic scientists conducting research at the nanoscale. I discuss the role of their disciplinary backgrounds, research interests and on-going research in the construction of their research identity. The first half of the chapter is partially generic in that I look at the construction of individual disciplinary background and the role of disciplinarity in everyday research activities. I contend that a division of labour exists between two main groups of scientists and that this affects individual identity construction through differing communication processes. In the second half I turn to the application of these analytical elements to NST and discuss scientists' perception of the field and how this affects their identity negotiation. The main emphasis of this chapter is on individual research practice and disciplinary research identity to provide the basis and frame for the next chapter on research collaboration, which picks up on the disciplinary affiliations that scientists narrate.

Disciplinarity in collaboration is the focus of chapter 5. I explore the emergence of, and motivations for, crossdisciplinary collaborations, and I look at the role and significance of disciplinarity and epistemology within collaborative settings. This connects to, and affects, the communication within collaboration and its scope. Therefore, I also enquire into epistemological impacts as well as into communicative elements, such as the organisation of information and knowledge exchange, and the significance of personality as a non-disciplinary aspect of collaboration.

In chapter 6 I pick up on the collaborative element by analysing the perceptions of academic scientists in their collaborations with industry-based researchers. The overall thrust of this chapter, however, lies in the relationship between scientists and non-scientists. In this study I analyse my respondents' perceptions of the role of collaboration with non-academic partners (industry), and of non-scientific aspects in their research. In this context I critically evaluate the notion of 'pure science', which reverberates in Moriarty's (2008) call for 'non-instrumental' science and refers to what can be described as the 'ivory towers' of academia (see also Jotterand, 2006). This chapter, therefore, expands my analysis slightly by embedding the issues (and themes) of disciplinarity, identity and collaboration into the wide context of accountability and research governance in changing academic science. I give one brief example of such accountability, and resulting strategies, by looking at funding strategies of scientists.

In the final chapter I review and evaluate my analysis to draw out the nature of this research field and its relationship to the 'knowledge society'. This chapter also provides room to present and discuss ideas and models that have emerged from the review of the debates around NST and my data analysis. I eventually discuss a series of wider questions and potential further lines of enquiry emerging from my analysis. I conclude with considerations of the generalisability of my findings from this case study of NST.

# Chapter 2: Locating Nanoscale Research in Science and Society



## 1 Introduction

Any literature review on 'nanoscience' and 'nanotechnology' relies upon the assumption that a distinguishable activity such as nanoscale research actually exists, that at least some proposed nanotechnologies are seen as potentially achievable and that there is a need for analysing the debates around and the understandings of research on the nanoscale. Of course, these constructions require agents and actions: scientists, propagandists, supporters, detractors and a diverse public, all of whom act, react and understand this particular research in certain ways. The existence of: a variety of articles and journals dedicated to nanotechnology; the founding of nanoscale research institutions; the actual research itself; funding bodies; narratives of how nanoscale research came into being; and the development of debates over the potentiality of nanotechnologies, all give reason to believe that there is such an entity called 'Nanoscale Science and Technology'. This material also suggests that the sociological engagement with NST is worthwhile as nanoscience and nanotechnology have become part of the academic world and are finding their way into the wider society. I attempt to give a wide-ranging review of the social scientific debates around NST; analytical concepts I rely on for my analysis; and aspects of the scientific demarcation debate on science and fiction in NST. The choice of contents contributes to the sociological construction of narratives of NST by emphasising certain agents, actions and aspects of nanoscale research.

## 2 A Brief History of NST

For millennia, humanity has applied different techniques of influencing matter from the scale of atoms and molecules up: baking bread, making ink, brewing beer, colouring sacral window paintings in houses of Christian worship. The methods applied to these and other ends have long relied upon naturally occurring biochemical processes at what is today called the nano- and the microscale. Before the invention of magnifying lenses and their combination into the microscope, all that was visible of these processes to the naked human eye, and thus phenomenologically comprehensible, were materials at the scale of at least a few hundred micrometres upwards. Thus, whilst self-assembly and self-organisation processes at the atomic and molecular level produced benefits, the actual changes of materials at the nano-level could not be made visible nor more profoundly controlled.

Alchemists, the esoteric ancestors of the modern chemists, looked into the invisible and unknown nature of the material world, trying to utilise 'obscure powers' – physical forces such as Brownian Motion, Van-der-Waals and quantum forces – in order to turn, for example, common metals into gold. Although alchemists failed to procure the 'philosopher's stone', by accident they discovered processes of making materials that had sustainable impact, as in the case of the 'European' porcelain invented by Johann Friedrich Böttcher in 1709, who initially attempted to make gold. For these enterprises, which were crude and inefficient ways of influencing material properties – difficult to control and unfit also for a cost-efficient production – they relied on an intuitive understanding of matter. To copy nature has remained a notion in chemistry today, probably even more so when concerned with the nanoscale. Such 'biomimetic' approaches are an example for that “that fundamental notion of alchemy [...] is still influential in today's chemistry” (Schummer, 2004a:17).

Nowadays, the commercial aspect of technology has become a greater driving force for research and development, as in the fields of biotechnology, genomics and artificial intelligence. Indeed, theoretical frameworks, or paradigms, seem to have become less important (Nordmann, 2004:52), with a stronger emphasis on technology-development and less on basic, theory-driven research. So strong appears to be the surge towards applicability that the development of a theoretical framework has become problematic. This is the case in NST. Here, quantum mechanics have been considered a useful starting point for a basic theory of NST, if the epistemic differences of understanding macro- and nanoscale physics can be overcome (cf. Vermaas, 2004). Developing an epistemology of nanotechnology has not been of general consideration until recently. This might be due to the commercial alignment of nanotechnology, but has its roots in the history of theoretical and technological development leading towards the ability to create images of atoms and molecules and move these. The pioneering inventions and insights of contemporary science and technology on the nanoscale have been achieved by researchers relying upon their theoretical frameworks of microscopy and physics such as the development of quantum theory in the early 20th century or the invention of the Scanning Tunnelling microscope (STM) and the Atomic Force microscope (AFM) in the late 1980s.

As a case in point, the science chemistry is based on paradigms, conceptual frameworks and theories; it follows universal scientific rules and a certain code of conduct, a disciplinary script. It has become a discipline in which many chemical processes can be replicated and even controlled because they are understood within a conceptual framework. Chemistry has engaged in teaching theories and methods, and has thus replaced the obscurity of alchemy. For the case of NST, self-assembly processes are being understood better with more research being conducted, tools being improved and funds increased for this specific area of chemistry. Scientists can prepare the grounds for chemical processes, thus aiming at the ability of 'directed self-assembly', a major goal of nanoscale research and crucial for manipulation at the atomic and molecular scale. Nanoscale research itself needs to leave obscurity behind, for example by developing a theoretical framework and setting viable technology-goals, should its protagonists aim for an academically integrated nanoscience. That may be either in a conventional form of a paradigm, or as something entirely different. However, the amazingly far- and wide-reaching promises and fears of the potential of NST are a major source of its current obscurity.

*Chronology of NST*

Any chronology of events and developments will remain subjective as it includes certain aspects, while excluding others, both depending on the narrator's knowledge and understanding of, as well as motivation for, the chronology. When looked at from a different perspective, certain aspects left out might seem more important than those included here. The linear chronology I present here, relies mostly on the narrative given by D.E. Newton in his publication on “recent advances and issues in molecular nanotechnology” (2002:107–120) and on a time-line conceptualised by C.M. Shea (2005:187). I have included dates and events from other sources, which are separately indicated, and have left out a number of events given by Newton and Shea. My focus here is on – in my view – major discoveries and innovations leading to today's NST, and its disciplinary aspects. When not explicitly pointed out, information in the *Occurrence*-column refers to Newton's text.

**Table 1: Selected Chronology of NST**

| *Date* | *Occurrence* | *Implications* |
|---|---|---|
| 400 B.C. | Greek philosophers Leucippus and Demetrius [Democritus] develop the concept of the 'atom'. | The then invisible atom is described as the basic, un-dividable unit of all matter. |
| 1803 | The English chemist John Dalton revives the idea of the atom being the smallest unit of matter. | Modern science's occupation with the scale of atoms begins. |
| 1908 | H. Lohmann uses the prefix 'nanno' (sic) in scientific literature (biology) to describe tiny organisms of what today would be measured as 200 nanometres in diameter (Joachim, 2005:108) | The biological aspect of 'nanno' is emphasised. A “vast literature exists about nannobacteria, nannoplankton and nannofossils” (Joachim, 2005:108). |
| 1953 | The German physicist Erwin Müller invents the | First images of atoms are provided by the FIM. |

| ***Date*** | ***Occurrence*** | ***Implications*** |
|---|---|---|
| | Field Ion Microscope (FIM). | A new understanding of microscopy is needed as atoms cannot actually be seen but imaged. |
| 1959 | The physicist Richard Feynman delivers his talk on the possibilities of deliberately influencing matter at the atomic level. | This talk is "[w]idely regarded as the first scientific discussion of nanotechnology" (Shea, 2005:187). Feynman voiced the hypothetical potential of engineering devices at the scale of atoms and molecules. |
| 1974 | "[T]he first discussion about single-molecular electronic devices came out in a 1974 paper by Aviram and Ratner with no reference to Feynman." (Joachim, 2005:108) | This instance suggest that Feynman's ideas might not have been the starting point for scientific occupation with molecular devices. |
| | Norio Taniguchi from Tokyo University distinguishes between microtechnology and "nanotechnology". (Shea, 2005:187) | Taniguchi is believed to have coined the term "nanotechnology" (cf. Joachim, 2005:108; The Action Group on Erosion, Technology and Concentration (ETC Group), 2003:18) and would thus have created a common label for engineering at the "sub-micrometer level" (Shea, 2005:187). |
| 1981 | German physicists Gerd Binning and Heinrich Rohrer invent the Scanning Tunneling Microscope (STM). | The STM allows for creating an image of the nanoscale by using a cantilever to 'sensor' the surface of individual atoms and molecules (cf. Jones, 2004). |
| 1985 | Richard Smalley, Robert Curl Jr. and Harold Kroto discover 'buckminsterfullerene', an almost spherical carbon-structure of approximately one nanometre in width (ETC Group, 2003:18). | Buckminsterfullerenes are very strong structures, that can be created by "vaporising carbon and allowing it to condense in an inert gas" (Shea, 2005:187). |
| | Gerd Binning, Christoph Gerber and Calvin Quate invent the Atomic Force Microscope (AFM), which is similar to STM, but actually touches the surface of the object instead of hovering one nanometre above it. | Improved images of the nanoscale by 'feeling' along the surface in intervals are possible. |
| 1986 | Physicist Eric Drexler's "Engines of Creation" is published. | The first non-technical book is "taking nanotechnology into the mainstream" (Shea, 2005:187). Drexler's book is related to the field of 'futurology' by a number of scientists (*ibid.*). |
| 1988 | The first formal course on nanotechnology is taught at Stanford University by physicist Eric Drexler. | The field of nanoscale research is beginning to enter academic teaching. No common paradigm for nanotechnology has yet been agreed on. Drexler's views are seen more critically today. |
| | First design and creation of a completely artificial protein with specific useful function at the E.I. du Pont de Nemours Company. | |
| 1989 | A first conference on nanotechnology is held. | A shared area of interest is developing, a first report on nanotechnology is given. |
| | IBM researchers move Xenon-atoms to form the logo of their company. | With no technical utility, this is the first deliberate rearrangement of atoms. |
| 1990 | The first artificial self-replicating molecule is devised at the Department of Chemistry at MIT. | |
| 1991 | Cornell University offers courses in | Nanotechnology courses are being established in |

| ***Date*** | ***Occurrence*** | ***Implications*** |
|---|---|---|
| | nanotechnology. | many academic institutions, at first as supplements and specialisations in the established disciplines, later on as stand-alone degrees. |
| 1993 | The first nanotechnology laboratory in the USA is established at Rice University (ETC Group, 2003:18). | Nanotechnology laboratories have been part of departments of established disciplines, but are increasingly re-labelled and focus on nanotechnology. |
| 1996 | Smalley, Curl Jr. and Kroto are awarded a Nobel Prize for the discovery of buckminsterfullerene. | "This cemented nanotechnology's reputation as a cutting-edge research field." (Shea, 2005:187) |
| 1997 | The first commercial enterprise in nanotechnology is founded in the USA (ETC Group, 2003:18). | The commercial prospects of nanoscale research have been fundamental in securing funds. |
| 1999 | Carbon tubes are discovered: "excellent conductors with amazing strength" (Shea, 2005:187). | Wide range of applications have been envisioned for carbon tubes (cf. Shea, 2005; Jones, 2004) |
| 1999/2000 | The National Nanotechnology Initiative is created in the USA. | Nanotechnology has become interesting to the political sphere due to optimistic economic prognoses. A small amount of all research funding is to be spent on exploring ethical, legal and social issues (ELSI) of nanotechnologies. |
| 2000 | "Lucent and Bell Labs, working with Oxford University, create the first DNA motors, demonstrating the convergence of biotech and nanotech." (ETC Group, 2003:18) | Nanobiotechnology, and within it nanomedicine, is an area that not only addresses the biological, but also stands for one possible paradigm of NST: the biomimetic approach to the nanoscale (in contrast to the mechanical and engineering approach of Drexler (cf. Schummer, 2004a:17)). |
| 2001 | Over one hundred entrepreneurs meet to discuss investing in nanotechnology at The Royal Society in the UK (Shea, 2005:187). | The commercial aspect of nanotechnology is supported by science oriented institutions, here The Royal Society. |
| | Richard E. Smalley and George M. Whitesides criticise Drexler's visions of nanorobots (all published in separate articles in the Scientific American) | The Drexler-Smalley debate continues for a time and shows attempts at demarcation of science fiction and possibilities in nanoscale research, but also difficulties in understanding other disciplines' approaches to the nanoscale (cf. Schummer, 2004c; Toumey, 2004). |
| 2002 | "IBM announces the development of a new electron microscope with resolving power less than the radius of a single hydrogen atom." (ETC Group, 2003:18) | The nanoscale becomes an incremental step towards even smaller levels of matter. |
| 2003 | At the Charité in Berlin, Germany, a particular cancer therapy using nanoparticles has been reported as being successful. (Berliner Kurier, 10.10.2003) | The reported success of a nanobiotechnological application supports the claims of great benefits in nanomedicine (cf. e.g. Freitas, 1999; Wood *et al*, 2003). |
| 2004 | The Royal Society and the Royal Academy of Engineering in the UK publish their report on nanotechnologies and nanoscience. | The report attempts to define the field of nanoscale research, enquires into ethical and social aspects, negotiates the scientifically possible and develops policy recommendations. It places great importance on public acceptability of nanotechnological applications. |

*Hopes and Anxieties of Nanotechnologies*

NST as a socially constructed field is infused with promissory and apocalyptic elements. They are widely discussed – both critically and positively – in numerous publications on technological as well as on social, ethical, legal, economic and so forth aspects of NST (for example Arnall, 2003; Bhushan, 2004; ETC Group, 2003; Freitas, 1999f). Indeed, many preliminary assessments of its potential are either so optimistic or so pessimistic – regarding the harm they might inflict upon humans and the environment – that "nanotechnologies are being shaped even before being born" (Wynne, 2004). This *a priori* shaping regards (1) the expectations set in nanotechnology, (2) the trajectories of nanotechnological innovation that are influenced by motivations and interests of researchers, funding bodies and the public, and (3) the short and possibly medium term unavailability of most of the technologies envisioned.

The nature of (future) nanotechnologies is described as being 'enabling' – providing new tools, products and possibilities – and as 'disruptive' – incorporating the capacity for profound changes in industrial practices, for the economy, and for society overall (cf. Jömann, 2004; Ryan, 2004). Promises of these new technologies include 'repairing' the environment, raising the standard of living, and providing cheap and clean energy (Johansson, 2003:5). Almost all aspects of life are thought to be affected, even entirely new aspects are expected to emerge (Jömann, 2004:22). Some of the more radical visions picture a revolution of production standards that will trigger a societal revolution (Johansson, 2003). Other radical views propose human enhancement and cyborgs, transgressing the borders between human and machine by integrating electronic and mechanical parts into the human organism (cf. Milburn, 2002).

Anxieties accompanying the emergence of NST are an integral reverse of invested hopes. Experiences with, for example, asbestos and nuclear power, both of which were hailed as positive scientific breakthroughs in their high times, seem to provide evidence to the necessity and rationality of being wary of nanotechnologies. Warnings refer to negative sides of their applications and to as yet unknown problems. Whereas the vision of a total takeover of the world by 'nanorobots' (grey-goo scenario, cf. Joy, 2000) has been deemed highly improbable by scientists (cf. Arnall, 2003:6; The Royal Society *et al*, 2004), toxicological dangers of nanoparticles (cf. ETC Group, 2003:24; Robinson, 2004:292), especially during production processes and at the end of the product life-cycle, have become a significant part of both the socio-ethical and scientific debate in NST. The very advantages of nanoscaled objects induce issues of their control and safety.

Thus, societal and ethical but also scientific concerns range widely. They address many points common in the assessment of emerging technologies: (1) public perceptions of novel technologies, (2) protection of civil liberties (for example surveillance via biosensors), (3) enhancement and a “'technical fix' view” of the human organism (The Royal Society *et al*, 2004:54), (4) 'dual use' (for warfare or terrorism), (5) control and regulation (governance and intellectual property rights), (6) convergence of research fields, and (7) organisation of access, use and control of technologies (for all: cf. Jömann, 2004; Rehmann-Sutter, n.d.; The Royal Society *et al*, 2004).

The aspect of potentiality in nanoscale research should not be underestimated. Nanotechnologies are being assessed and envisioned before their actual innovation processes, or in the early stages of development. This can be positive, if the process of assessment and control adopts a kind of 'reflective co-evolution' (Rip, 2002). This is an evaluative element depending on collaboration between academia, industry and the public sectors to shape research trajectories and negotiate ethical and governance issues at the same time. However, uncertainty and arguments of the 'slippery slope' kind can lead to calls for a full or partial stop to research, as in the case of the The Action Group on Erosion, Technology and Concentration (ETC group) demanding a moratorium on commercial nanoparticle production (2003:25).

*Processes of Institutionalisation*

Proportional to the strength of an idea becoming established in a scientific environment, infrastructures emerge: new institutes and laboratories, regulatory frameworks and teaching structures, funding bodies and initiatives. This process of NST institutionalisation has taken place for some time, probably starting with the establishment of a formal course in nanotechnology at Stanford University in 1988. Since then, numerous conferences on nanotechnology have been held. Many institutions dedicated to nanoscale research have been founded, such as the Institute for Molecular Manufacturing (IMM) and the Foresight Institute – both influenced by Eric Drexler's work on atomically precise engineering, but dissociated from him today; the Institute for Nanoscale Science and Technology (INSAT) at Newcastle

University in 1999; or the Kavli Nanoscience Institute (KNI) at the California Institute of Technology in 2001. Existing organisations and institutes have taken interest in nanotechnologies (Greenpeace, ETC Group, Meridian Institute, The Royal Society). National and international initiatives to support and fund NST have been created in the US, Europe and Asia. A range of teaching courses in nanotechnology, both under- and postgraduate, have been set up: a PhD in Nanotechnology at the University of Washington, Seattle/USA; a BSc in Nanotechnology at Flinders University, Adelaide/Australia; under- and postgraduate programmes in Electronic Engineering with Nanotechnology at the University of York/UK; BSc and MSc programmes in Nanosciences at the Universität Basel/Switzerland; and at the Universität des Saarlandes/Germany a physics and engineering programme in Micro- and Nanostructures, to name but a few.

The example of teaching provides evidence of an interesting conflict in the institutionalisation process of NST. Teaching in academia requires a clear curriculum: a shared set of theories, methods and tools. In the case of nanotechnology, many different disciplinary curricula co-exist. University courses are usually organised within the frameworks of individual disciplines and often specialise in only one aspect of NST. Although some politically active scientists in the field relate their research to nanoscience, such as professor of Physics Michael L. Roukes (2002:vii) or professor of Chemistry and vice-president of the Royal Society Julia Higgins (at a DEMOS workshop on 'Governance at the nanoscale', 06.04.2006 in London), NST has not become a fully represented discipline with regular curricula. That is not to say that there are no university chairs dedicated to nanotechnology. Cranfield University/UK, hosts a professorship for 'Nanotechnology and Advanced Materials' in their Materials Department. The University of Arkansas/US features one in 'Nanotechnology and Innovation' in the Physics Department, whilst Newcastle University/UK introduced a professorship in 'Nanoscience/Nanotechnology' in 2007, based at the School of Electrical, Electronic and Computer Engineering. These professorships and their institutional contexts imply that NST is seen as a specialisation in established disciplines. It features some disciplinary characteristics, such as the establishment of a research and funding infrastructure, but falls short of distinguishing itself from existing fields by constructing an epistemological framework. At the same time, NST could be a foundational science and technology field, merging developments and advances of established sciences in technologies on the nanoscale.

# 3 Theoretical Framework and Key Concepts

Terming NST a science, however, appears to be imprecise. The combination of science and technology is not part of the traditional understanding, that is as a clearly distinguishable binary of science and technology. Science is expected to provide a theoretical framework, whilst technology applies findings and knowledge generated by science. For emerging research fields, these two central concepts have been described as changing entities with increasingly diffuse borders, both in relation to each other and to society (e.g. Haraway, 1997; Nowotny *et al*, 2001; Nowotny, 2003; Rip, 2002). For my analysis I rely upon a certain understanding of science and technology and their key concepts. I clarify these on the following pages.

*The Sociological Framework: SST and STS*

Sociology of Science and Technology (SST) and Science and Technology Studies (STS) provide the general framework for my study. SST is a specialised field of sociology as it focuses on science and technology, but it is also a general approach of sociology in that it "is addressing a set of questions central to all sociology" (Star, 1988:197):

> "How do people come to believe what they believe about nature and social order? What is the relationship between work practices and social change? What is the trajectory of social innovations? Who uses them and for what purpose? As people from different worlds meet, how do they find a common language in which to conduct their joint work? How can we study people's work critically and sociologically yet respect the categories and meanings they generate in the process? Finally, what are the boundaries between organism and environment; how fixed are they; how can we know them; and are they meaningful a priori?" (*ibid.*)

Thus, it addresses the "human side of science", as Stephen Cotgrove put it (1970:1). Many of the questions in this quotation are constitutional for my study. SST and STS are closely connected in their contexts and aims. The SST-aspect becomes apparent in my analysis of how researchers construct NST; in exploring notions of disciplinarity in science practice; and in examining what impact changes in research practice may have on academic science. The STS framework contributes a more problem-orientated approach to understanding knowledge production. Here, researchers' experiences in collaboration and their identity negotiation are of particular interest. The combined approach of SST and STS, in turn, benefit the analysis of changes emerging in academia through the increasing permeability of institutional borders in knowledge production. In addressing these and other questions, I continuously refer to concepts such as 'disciplinarity', 'boundary work', 'trading zones' and 'technoscience'. I provide a brief overview of the main concepts here.

*Disciplinarity and Collaboration*

Science and its disciplines are social systems constantly (re-)constructed by humans. Different epistemologies and problem-areas emerge according to scientific interest, understandings of reality and the focus in approaches to the world. Frameworks of theories, methods, tools and interpretation-frames evolve, which act as boundaries of how understanding can be achieved and which knowledge is deemed appropriate. This way, schools of thought are established that aim to distinguish themselves from other schools. They produce epistemic cultures, which create and then legitimise this knowledge (Johansson, 2003:4). This connects to recurring identity negotiation, to affiliation with disciplines and means of knowledge production. 'Boundary work' is part of identity negotiation. It draws on respective frameworks and is an integral part of sustaining a school of thought such as a discipline, a way of knowledge production such as science, or an encompassing culture of knowledge production such as academia. The production of knowledge, its evaluation and its proliferation are part of the competition for a 'superior' understanding of the world. Thus, a scientific discipline consists of two elements,

> “(1) a body of knowledge, including concepts and beliefs (knowledge of objects), methods for increasing and securing knowledge (knowledge of methods), and values about judging the quality and importance of knowledge (knowledge of values); (2) a social body with effective rules and means for increasing, communicating, and teaching the body of knowledge as a way of reproduction.” (Schummer, 2004a:11)

The individual scientist stands in constant exchange with the scientific community (Cotgrove, 1970:12), both relying on each other to create meaning (cognitive aspect) and to pass on or negotiate meaning to maintain the scientific community or school of thought (social aspect). A unique ‘language’ for everyday work is created – simplifying collaboration among researchers of one school of thought – a ‘habitus’ (cf. Bourdieu, 1987) of the discipline emerges. Researchers from within the same theoretical framework collaborate to maintain and develop knowledge production within their discipline. At the same time, 'crossdisciplinary' collaboration takes place between researchers from different disciplinary backgrounds. This renders knowledge and framework negotiation more difficult, but is increasingly necessary for progress in scientific knowledge.

'Trading zones' (e.g. Gorman *et al*, 2004; Rip, 2002) are fora of communication in such crossdisciplinary collaboration. They are significant for avoiding, as Thomas Kuhn (1993) put it, the 'incommensurability' of disciplinary languages and cognition. When, as in the case of NST, many diverse disciplines come together in projects, interpretation of different expertise and methodologies becomes necessary. This can be achieved through the standardisation of tools and techniques (Star and Griesemer, 1989:407). Within trading zones, 'boundary objects' can evolve during interaction. These “are common objects which have the same boundaries but different internal content [due to] different means of aggregating data” (*ibid.*:410), such as the 'molecule' can have different meanings to biologists and chemists. Boundary objects are located between two or more different social worlds to “make information compatible [...] across divergent [social] worlds” (*ibid*:407). They can be used by representatives from these different worlds “for specific purposes without losing their own identity” (Guston, 2001:400). Thus, boundary objects can provide the grounds for inter- and transdisciplinary collaboration. Many of these boundary objects are artefacts, developed by one area and applied in others. As tools they influence the way researchers produce knowledge and play an enabling role, such as microscopic devices in NST that allow to visualise nanoscaled objects.

Trading zones and boundary objects support crossdisciplinary collaboration, of which three types dominate in the literature: multi-, inter- and transdisciplinarity. An attempt at distinguishing the disciplinarities in regard to their collaborative nature is given by Van den Besselaar and Heimeriks:

> “Thus, in multidisciplinary research, the subject under study is approached from different angles, using different disciplinary perspectives and integration is not accomplished. Interdisciplinary research leads to the creation of a theoretical, conceptual, and methodological identity, so more coherent and integrated results are obtained. Finally,

> transdisciplinarity goes one step further and it refers to a process in which convergence among disciplines is observed, and it is accompanied by a mutual integration of disciplinary epistemologies." (Van den Besselaar and Heimeriks as cited in Morillo *et al*, 2003:1237)

Following this proposal, the three concepts are distinguished by different grades of epistemological integration, thus reflecting the utility and extent of 'trading zones' as places of communication.

Generally, multidisciplinary collaboration describes research in which different disciplines are involved (Schummer, 2004b:444) but do not necessarily work across boundaries. A far more discussed disciplinarity, especially in the context of NST collaboration, is interdisciplinarity. This concept is considered to be elemental to nanoscale research (e.g. Arnall, 2003; Wood *et al*, 2003). Interdisciplinary work was introduced in the early 20th century as a "management tool [...] in industrial research laboratories" (Pestre, 2003) to solve technological problems. Interdisciplinarity in academic practice can similarly be seen as an attempt to address increasingly complex problems in science and technology whilst expanding the understanding of the material world by adding different disciplinary perspectives. In new fields of research, the level of interdisciplinarity is regarded as being generally higher than in established disciplines (Morillo *et al*, 2003). However, disciplinary boundaries appear to remain in the assessment of the quality of interdisciplinary work (Mansilla and Gardner, 2003). The study of practically applied interdisciplinarity is still in its infancy (Schmidt, 2004:35) despite a strong usage of the concept in debates around science and technology innovation.

Transdisciplinarity, a more recent concept of collaboration, is characterized by Nowotny (2003) as an integral part of contemporary crossdisciplinary and cross-institutional knowledge production. Nowotny *et al* (2001) connect transdisciplinarity to the concept of 'Mode-2' knowledge production, describing the transgressing of institutional boundaries within and between science and society in the production of knowledge. Combining interdisciplinarity with the parallel transcendence from disciplinary focus has been another uptake of transdisciplinarity (Giri, 2002) that emphasises personal interaction in research collaboration orientated at problems outside the disciplinary structure of academic science.

In summary, these three concepts of disciplinarity describe very different approaches to research collaboration. They provide means to analyse organisation and practice of knowledge production. However, they lack a comparative potential to examine the role different disciplinary expertise take on in and through crossdisciplinary research collaboration. The concepts of trading zone and boundary work can help in exploring this and other elements of crossdisciplinarity further.

*Concepts of Science and Technology Studies*

NST as an area of sociological enquiry poses difficulties for its analysis in the context of traditional, established disciplines (cf. Nordmann, 2004:52). Therefore, in this study I rely on theoretical concepts that address understandings of science and technology different to the approaches of classic theories of modernity (cf. Latour, 2000). One of these is 'Mode-2 knowledge production' in which scientific endeavour is “increasingly carried out in the context of application” (Nowotny, 2003). That context is a result of open-ended communication among various stakeholders. Participants in these processes come from science and society alike (Nowotny *et al*, 2001:201ff).

Technology assessment is another approach to tying together scientific and social aspects in research towards socially robust science output. Increasingly complex scientific and technological problems are thus to be addressed in their societal context. Doing so requires the transgression of scientific disciplinary and societal sectoral boundaries, mutually influencing their cultures, knowledges, practices and outlooks. 'Bioethics' is an example of this. The domain of the ethicist shifts and its defined limits blur in practice (cf. Haimes, 2002; Haimes and Williams, 2007). This 'blurring of boundaries' is generally present in scientific conduct (cf. Bogner, 2005), and meanings of categories are shifting or waning. Hybrid entities (Latour, 2000) emerge to manage greater expectations and requirements in society.

One such hybrid entity is 'technoscience' (cf. Haraway, 1997), a conglomerate of applied science, technology and societal interests. Boundaries between scientific knowledge and technology production blur already in the agenda-setting; and scientific enterprise is paired with technological application. At the same time, societal interests impact on trajectories of science and technology production through accountability processes. A third aspect is that scientific research is directed at technological advancement. Technological testing, for example generating artificial hybrids such as “transgenic mice” (Nordmann, 2004:58), becomes an integral part of scientific enquiry. At the same time, the notion of a 'pure science', of knowledge production devoid of societal aspects, is withering (cf. Khushf, 2004), and rightly so. Applied science is an integral part of technoscience, where research is conducted towards application in science and society. In nanotechnology the aim appears to be a more profound ability to change the material world and commercial viability.

I believe that the idea of technology assessment (TA) connects rather well here. TA is described by some as part of 'responsible innovation' (Rip, 2005), which acknowledges and includes “social aspects, desirability and acceptability” (*ibid.*) of technologies before (if possible) and during the innovation process (for real-time TA see Guston and Sarewitz, 2002; for midstream modulation see Fisher and Mahajan, 2006). In the case of nanotechnologies, TA incorporates a wide range of aspects in the examination and prognosis of new technologies: ethical, economic, environmental, legal and social aspects (E3LSA). The difficulty hereby lies within determining *possible* future applications. Demarcating visions from scientific probability becomes not only a task of natural sciences, but also part of the social scientific study of science and technologies.

The concept of technoscience, therefore, describes activity that reaches beyond the production of scientific knowledge as reflected in the academic-scientific notion of 'pure science'. Societal interests influence scientific activity, and boundaries of all kinds are transgressed in the production and interpretation of knowledge and technology: between disciplines and claims of knowledge; between academia, commerce and society; between cultures of knowledge production.

*Gigantic Space at a Tiny Scale: Nano, Micro and Meso*

For NST, scale plays a determining role in scientific and societal terms, providing a strong rationale for the field. The smaller functional units become, the less space is needed whilst at the same time a higher density of units in one place is possible. But not only space is of concern. The changing physical properties of matter at the scale of atoms provide another legitimation strand for NST, allowing the creation of novel materials and new applications.

**Table 2: Locating NST - Overview of Scale**

| Scale | | Phenomenology | Nanotechnology |
|---|---|---|---|
| Macro | | *Lebenswelt*; accessible without advanced technical artefacts;<br>direct visual and tactile contact and control | nanotechnologies are devised for utility of/in the macro world; control of nanotechnologies via macro-technologies |
| Meso | | accessible through existing macro-technology such as microscopes | intermediate zone between macro- and upper nanoscale |
| | Micro | same physical effects as in macro-world;<br>visual access through technology;<br>objects: bacteria, blood cells etc. | microtechnologies connect nanotechnologies with macro-world and allow for their development, utilisation and control |
| | Current 'Nano' | access via naturally occurring mechanisms or through limited top-down engineering;<br>visual image through tactile contact (cantilever technology)<br>objects: large molecules, viruses etc. | most temporary nanotechnologies are in the range of several hundred nanometres and micrometres, also referred to as “mesoscale engineering” (Stix, 2001:8). |
| Real Nano (of NST visions) | | physical effects drastically different to macro- and meso-world;<br>objects: small structures of atoms and molecules (DNA) and below | prognosticated nanotechnologies constructed at the atomic and molecular level |

Considering the understandings of these scales, most applied nanotechnologies are still working at the microscale (Stix, 2002:7ff). For future applications at the atomic level, the nanometre might be too large a unit to clearly differentiate (Joachim, 2005:108). In light of these argumentations, the prefix 'nano' could be seen as an *interim* solution, but it has not been devised to be that. In fact, it has become integrative to NST visions, fears and understandings. In table 2 I acknowledge the different technological connotations of 'nano' by dividing scale into 'current' and 'real' nano.

The scale lies at the heart of understanding NST because the social debate trying to define the field takes its main notions – enabling and disruptive – from the potential that control over matter at the nanoscale and below will allow. But even the scientific understanding of what identifies nanoscale research is still diffuse.

*Nanoscale Science and Technology*

Despite their seemingly ubiquitous presence in science today, opinions on the concepts 'nanoscience' and 'nanotechnology' differ in definition, their position in academia, indeed their differentiation.

## Chapter 2: Locating Nanoscale Research in Science and Society

> “Roughly speaking, *nanoscale research* concerns molecular architecture, *nanotechnology* aims for the control of this architecture, and *nanoscience* investigates the physical properties that depend on it.” (Nordmann, 2004:51; emphasis by author)

Alfred Nordmann, a social scientist, emphasises the overlapping of concepts. For him, 'nanoscale research' is a distinct area in NST. However, I use that term as a generic descriptive, encompassing nanotechnology and nanoscience. For my further analysis of the field it is therefore important to provide an overview of the essential concepts I use.

There is a vast amount of information available on the subject, but authors and institutions fail to deliver concise and unified conceptualisations for either nanoscience or nanotechnology. Nanotechnology is the most commonly used term in science and society for the phenomenon of research on the nanoscale. Both physical and social sciences authors describe NST as multi- or interdisciplinary, material- and application-orientated, and targeted at the control of atoms and molecules.

*Nanoscience*

A number of scientific and social scientific authors apply the term 'nanoscience' as a synonym for nanotechnology or remain unclear about a fundamental distinction between the two concepts (for example ETC Group, 2003; Mnyusiwalla *et al*, 2003; Rey, 2003). Nanoscience, however, implies a claim different to nanotechnology, a claim to a theoretical foundation. The traditional understanding of science is that it supplies an epistemological framework. The term nanoscience, then, suggests a paradigmatic approach to the nanoscale through a number of theories, methods and codes. It is in fact already referred to as a discipline or science by authors across the spectrum of stakeholders (for example Roukes, 2002; The Royal Society *et al*, 2004:5; Wood *et al*, 2003:6). However, in practice there is a lack of a unified epistemology in the area of nanoscience (Joachim, 2005; Nordmann, 2004) to render it a discipline. Instead, many diverse scientific, or disciplinary, backgrounds claim a part in the nano-endeavour. This supports the idea of a crossdisciplinary nature of NST and implies the need for a 'nexus' (Rip, 2002), or for boundary objects, for researchers to communicate across the borders of the different contributing disciplinary frameworks. These boundary objects might lay the foundation for an eventual emergence of a discipline nanoscience. On the other hand, quantum physics and molecular biology already serve as epistemological frameworks.

The definition of nanoscience provided by the Royal Society *et al* (2004) is so broad that it can apply to all scale-dependent research areas, for example colloid chemistry or molecular biology. The main thrust, however, is the exploration of the *significantly* differing properties of nanoscaled matter. In the 2003 ESRC-report nanoscience has been defined as

> "[…] a convergence of physics, chemistry, materials science and biology, which deals with the manipulation and characterization of matter on length-scales between the molecular and the micron size." (Wood *et al*, 2003:6)

This model takes a unifying standpoint of nanoscience as a fundamental and interdisciplinary research field. The definition is representative for most attempts in that it avoids to clarify the academic position of nanoscience. It remains a "gigantic combined science-technology field for scientists and engineers" (Joachim, 2005:107), leaving much room for interpretation. Again, one major characteristic of nanoscale research lies within the shared expectations of major achievements by scientists from different disciplines (Rey, 2003:26).

However, the continuing need for a focused categorization might be an indicator for the current positioning of nanoscience in academia. The state of affairs of nanoscale research at universities and research institutes might indicate an additional possible understanding of nanoscience. This entity is either a specialisation of existing fields or it is in the preliminary stages of an academic discipline. It might become a discipline in its own right by adopting theories from contributing sciences, but also by modifying and adapting these to the nanoscale. In the case of quantum mechanics, finding one common interpretation of physics at that level might be part of establishing a theory of nanoscience (cf. Vermaas 2004).

One trajectory of nanoscience's development remains within the theoretical framework of Thomas Kuhn's paradigms, but might possibly address a broader and shallower spectrum. On the other hand, nanoscience may be part of a return to holistic approaches to the world (Johansson, 2003:4). In that case, nanoscience and nanotechnology will, however, form one single hybrid in the context of 'Mode 2 knowledge production'.

*Nanotechnology*

Definitions of nanotechnology generally incorporate more details about what it aspires to than those of nanoscience, and it remains connected to existing sciences. Visions of technological potential feature heavily. A unified understanding of what the area of nanotechnology is about might improve communication within the research community as well as between researchers, funding bodies, legislators and the public. But because nanotechnology as a term stands for such a broad range of *nanotechnologies* – differing in design, method and application – it seems impossible to produce a sufficiently clear definition. Its crossdisciplinarity has been described by scientists as being "a characteristic of emerging engineering disciplines" (Theis, 2001:75), whereas its focus on the development of new materials might also render it, for example, a material science. The question is, however, if nanotechnology can be defined as something still quite as focused as engineering or material science. At the same time, technological development at the nanoscale necessitates the utilisation of existing approaches and shaping of novel ones from these as physics change at the nanoscale. Because quantum mechanics allow physical states impossible at larger scales, paradigms of established disciplines may fail to grasp and describe technological processes at the nanoscale (cf. Jones, 2004; Vermaas, 2004). This does not necessarily become clear in existing definitions.

> "Nanotechnology is *defined in terms of scale*. It describes materials, systems & devices […] in the range 1-100 nanometre. […] It enables *controlled component design and fabrication* on atomic and molecular scales [and] unites findings and processes from biotechnology and genetic engineering with chemistry, physics, electronics and materials science with the aim of *manufacturing cost-effective innovative products*." (Institute for Nanotechnology Exploitation (now: INEX), 2006; emphasis added)

> "[…] any technology performed on a nanoscale that has *application in the real world*. […] Nanotechnology encompasses the *production and application* of physical, chemical, and biological systems at scales ranging from individual atoms or molecules to submicron dimensions, as well as the *integration of the resulting nanostructures into larger systems*." (Bhushan, 2004; emphasis added)

Four dimensions seem to constitute the understanding of nanotechnology: (1) the technological practicability at working on the nanoscale, (2) the crossdisciplinary range of knowledge and methods, (3) the material connection of nano-, meso- and macroworld, and (4) commercial exploitation. The integration of these dimensions is based on research collaboration between established sciences.

A third attempt at defining nanotechnology provides an example of the “huge gap between lay people's expectations […] and the scientists' awareness of the problems involved in achieving them” (Johansson, 2003:6). Nanotechnology, defined by the Merriam-Webster's Collegiate Dictionary, is “the art of manipulating materials on an atomic or molecular scale especially to build microscopic devices (as robots)” (as cited by Sims Bainbridge, 2004:1136). 'Microscopic devices' such as the mentioned robots feature in popular science fiction, for instance in the novel 'Prey' by Michael Crichton (often referred to by social scientists), or as part of the cyborg life-form 'Borg' in Star Trek. However, the possibility of creating systems as complex as robots at the atomic or molecular scale is considered highly improbable by many scientists (e.g. Rey, 2003; Whitesides, 2001) due to the difficulties of predicting and controlling forces at the atomic level, such as Brownian motion and quantum forces, by nowadays available technology.

Two (existing) paradigms of nanotechnology have been at the centre of attempts to understand NST: (1) the *biomimetic* approach of 'bottom-up' processes such as self-assembly and directed self-assembly, which relies on biochemical processes, approaching the nanoscale from a more organic perspective, and (2) the *engineering* approach of a mechanical perspective on the nanoscale: building atom-by-atom (Schummer, 2004a:17). The second approach follows conventional 'top-down' approaches of engineering, still strongly supported by many scientists: “we need to apply at the molecular scale the concept that has demonstrated its effectiveness at the macroscopic scale” (Merke as cited in Dupuy and Grinbaum, 2004:4). These two paradigms apparently connect to certain established disciplines: (1) biology and chemistry, and (2) engineering and applied physics. They project methods, theoretical frameworks and perception of objects at the nanoscale, that influence the complete understanding of what NST can be about.

Summarising my exploration of nanoscience and nanotechnology, I believe there is still no common understanding of these two concepts. Their different uptakes, both on their own and in comparison, indicate that the field of nanoscale research is still emerging and forming its scientific identity whilst its social identity is very much established already. However, it seems very difficult to separate the two areas in an attempt to understand and define the field of nanoscale research. Therefore, I contend that it makes more sense to consider the novel nature of the field by exploring the hybrid nature of NST, and the technoscientific understanding of it.

*Nanotechnoscience*

In many cases the use of the concept of nanotechnology suggests that it is understood as a conglomerate of science and technology, where scientific knowledge is produced for and in lieu with technological development. I follow this trajectory by using the concept of Nanoscale Science and Technology (NST) in my research. This approach combines both research and applications at the nanoscale, and draws from the hybrid concept of 'nanotechnoscience' (e.g. Bennett, 2004; Nordmann, 2004; Schwarz, 2004). The concept 'nanotechnoscience' is used predominantly across the fields of humanities and social sciences, and it indicates a socio-critical examination by its users. The construction of NST in the public and in academia is here seen as the overlapping of technology and science, and with science policy.

Authors adapting the notion refer to the social impact NST may have, and to the blurring of boundaries and redefinition of social categories. Understanding NST as nanotechnoscience indicates that emerging trajectories of knowledge and technology production are influenced by societal interests. At the same time, nanotechnoscience problematises 'technological reductionism' (Schmidt, 2004:36). Constructing a theoretical framework plays here only a secondary role, secondary to the task of finding or creating new products (Nordmann, 2004:59). To integrate social, ethical and so forth considerations in NST knowledge production becomes imperative as in this field the nature of science might change considerably, redirecting the scientific positivist aim of explaining the world towards taking on and changing it – as the slogan “Shaping the World Atom by Atom” (Nordmann, 2004:59) implies.

*Nanobiotechnology*

As a specialised branch of nanotechnology, research in nanobiotechnology merges physics and engineering with material science, biology and chemistry. It integrates nano- and biotechnology at the 'wet/dry interface' of biological systems and nanomaterials (ETC Group, 2003:32). Natural 'nano-machines' such as viruses or ribosomes, the DNA and chemical self-assembly processes represent, among others, starting points for nanotechnology in the biological realm. The chemist George M. Whitesides (2001) suggests that nanotechnology will profit from the inclusion of biological and chemical principles much more than by holding on to traditional mechanical approaches in engineering. 'Biomimetics' draws on principles and systems that have evolved over millennia (e.g. Ball, 2002; Salata, 2004; Siegel *et al*, 1999:126; Whitesides, 2001), copying existing biological 'nanomachines' in order to *deceive* nature (cf. Ball, 2002:R18), using and reproducing biochemical principles and materials via templates, scaffolds, layering (*ibid.*). Although first applications are already available for commercial use (cf. Salata, 2004), the focus of nanobiotechnological research is still “to obtain a detailed understanding of basic biochemical and biophysical mechanisms at the level of individual molecules” (The Royal Society *et al*, 2004:20).

An alternative term to nanobiotechnology is 'bionanotechnology'. The order of prefixes 'nano' and 'bio' may depend on different understandings of the epistemological grounds: (1) localising nanobiotechnology in the tradition of biotechnology, or (2) seeing bio-nanotechnology as the occupation with the biological in the context of the new nanotechnologies. Following this train of thought, nanobiotechnology refers to the occupation with the nanoscale in the realm of biotechnology.

> “Nanobiotechnology is the *convergence of engineering and molecular biology* that is leading to a *new class of multifunctional devices and systems for biological and chemical analysis* with better sensitivity and specificity and a higher rate of recognition.” (Fortina *et al*, 2005:168, emphasis added),

Bionanotechnology, then, refers to the aim of integrating biological components in nanotechnological application:

> “Bio-nanotechnology is concerned with *molecular-scale properties and applications of biological nanostructures* and as such it sits at the interface between the chemical, biological and the physical sciences. (The Royal Society *et al*, 2004:20, emphasis added)

Here, the properties and applications of molecular natural structures are emphasised, both aspects featuring prominently in the agenda-setting of nanotechnology. This attempt at an analysis might be futile, though, if the use of two different terms is simply further evidence of the lack of common definitions in NST. Most literature does not consider reasons for the use of different terminology. However, there are some attempts at distinguishing both terms, for example made by the European Network of Excellence Nano-2-Life. Whether nanobio or bionano, both refer to nano-objects, nano-devices and nano-electronics such as molecular motors, biosensors, nano-cantilevers and optical tweezers, thus have common goals and approaches.

*Nanomedicine*

Many prognoses refer to the health sector as the major field for nanobiotechnological applications (cf. Salata, 2004). In the long term, improved implants and tissue-growth on scaffolds – comparable to hopes in stem cell research to grow entire organs – are considered possible (Wood *et al*, 2003:21). These expectations imply an understanding of nanobiotechnology as benign, supported by the focus on 'nanomedicine'. Indeed, much of the literature on nanobiotechnology refers to nanomedicine as a field of application, whereas the amount of literature on nanomedicine seems to be greater than nanobiotechnology in the first place. As the field centres around the human body and health, this situation is not so surprising. Instead, a greater public awareness can be expected.

> "The field of 'Nanomedicine' is the science and technology of diagnosing, treating and preventing disease and traumatic injury, of relieving pain, and of preserving and improving human health, using molecular tools and molecular knowledge of the human body. [...] The aim of 'Nanomedicine' may be broadly defined as the comprehensive monitoring, control, construction, repair, defence and improvement of all human biological systems, working from the molecular level using engineered devices and nanostructures, ultimately to achieve medical benefit. In this context, nanoscale should be taken to include active components or objects in the size range from one nanometre to hundreds of nanometres. They may be included in a micro-device (that might have a macro-interface) or a biological environment. The focus, however, is always on nanointeractions within a framework of a larger device or biologically, within a sub-cellular (or cellular) system." (European Science Foundation (ESF), 2005:7f)

The ESF has chosen a wording that is almost identical to the description of nanomedicine given by Freitas six years before. Freitas' expectations of “Basic Capabilities” of nanomedicine (1999) are rather visionary, and the realisable potential of nanotechnology in medicine is not unchallenged among researchers in the field (cf. Rey, 2003:28).

Social and ethical aspects of nanomedicine are comparable to the considerations in nanotechnology but address more specific aspects regarding the human body and health. As medicine resorts to different evaluative strategies regarding risk and advantage in diagnostics and therapies than, for example, engineering, the consideration of technologies by stakeholders will likely be more lenient.

*Defining for Specific Audiences*

Definitions address different audiences: commercial enterprises, scientists, media and the publics, and political agencies with their own agendas. Catering for their interests keeps the understanding of NST diffuse, even fluid. Arguably, 'nano' has become a label that draws funds just like biotechnology and genomics have done before. Claiming incremental advantages from established sciences (Arnall, 2003:5), the prefix 'nano' is used to generate awareness of the field's potential, particularly its commercial potential (*ibid.*:6). Nanotechnology and nanoscience constitute a highly diffusely constructed field with little disciplinary institutionalisation but a strong narrative impact. Funding streams and funding organisations seem to influence the trajectories of research. The agenda of referring to NST and 'building it up', it appears, is to gain funding for otherwise 'boring' technologies, devised by existing physical sciences and difficult to convey as an exciting enterprise.

In regard to social and ethical aspects of NST, there is a strong tendency among social scientists to anticipate parallels between the public perception of NST and the experience with genetically modified organisms (GMO) (Schummer, 2004c; Toumey, 2004; Wynne, 2004). As scientists and policy makers seem to be influenced by such debates in their decisions on approaching and presenting nanotechnologies, former experiences in adjacent fields, such as biotechnology and genomics, play a vital role in the narration of NST.

> “Engineers and policy makers seem to have learned from the past, notably from the consumer disaster with genetically modified organism and from debates about the Human

> Genome Project, that ethical and sociological reflection should accompany and not follow technological research and development." (Schummer, 2004c:56)

In a similar way, financial support to nanoscale research may well be compared to the funding of the Human Genome Project (HGP), which, as a single scientific project with no directed commercial application, has had public funding of over US$ 3 billion in the US alone. The HGP set out to map the entire human genome to better understand it as well as support the development of methods to prevent genetically induced diseases; in short, it was a very ambitious promise to gain funds. Primarily, the project resulted in a consolidated understanding of the high complexity of the human genome. The actual outcome of NST may fail short of its promises – and concerns – in a similar way. Promises and exciting visions have drawn vast investments into nanoscale research nonetheless, anticipating a market of up to US$1 trillion for nanotechnology in the near future (Schummer, 2004c:69).

The rapid sequence of very basic innovations and discoveries in the field have, together with the promises of nanotechnology and the availability of enormous funding, rendered nanoscale research 'en vogue' and financially worthwhile. Nonetheless, great economic and societal profits are as yet outstanding. NST has so far been a process of tiny steps, not of giant leaps, with most research taking place at the basics. Still, as a result of the availability of funds, research institutes have been renamed (Johansson, 2003:3) and on-going research projects allegedly re-labelled (Wood *et al*, 2003:5) to share in the hype. This occurs despite the scientific community being "a little unclear about what [nanotechnology] really means" (Stix, 2001:8).

## 4 A Social Scientific Analysis of NST

NST narratives seem to have a significant impact on decision-making regarding its funding and position in science, on its perception and development. They have been constructed by social scientists enquiring in the field, as well as by physical scientists, clinicians and engineers working at the micro- and nanoscale. Interviewing researchers in the field has provided me with understandings of their identity and research practice as well as their understanding of NST. I analyse and present these narratives along certain themes in chapters

4-6 of this thesis. Here, I take an introductory glance at (1) the role of promises and fears as a kind of stakeholder-engagement in nanotechnology, (2) two dominant origin myths of NST, and (3) the role of technology assessment in narrating nanotechnology. Consolidating several perspectives on narratives in the literature I distinguish between a 'futurist' and an 'evolutionary' strand of NST. The label 'futurist' reflects on this narratives' very close proximity to a 'nano-futurology'. For the second strand I apply Richard Jones' (2004) terming of the 'evolutionary'. Scientific evolution here is an organic and incremental development of technologies not necessarily towards a certain kind of technology, for example nanotechnology, but towards the aim of deeper enquiry into and greater mastery of the world.

*Promises and Fears: From Science Fiction to Science Facts?*

What makes nanotechnology so interesting is the great possibilities that are communicated by nano-enthusiasts and their funders. The field of biotechnology – in presenting exciting projections of future technologies – has had a similar impact.

> “[D]ebates about biotechnology provide the immediate context for understanding why nanotechnology is now gaining significant attention, this does not necessarily mean that the two will necessarily follow the same trajectories”. (Pidgeon, 2004)

The assessment of social, ethical and so forth aspects has been an integral part of research in NST from early on, in parts required by funding regulations. This is considered to be a direct outcome of the experience with GMO (cf. Schummer, 2004c; Wynne, 2004), even though parallels should not be drawn too far (cf. Marris, 2001). The 'nano-futurology' – an array of hopes and anxieties – and its reiteration through scientists, investors, entrepreneurs, policy makers and watch groups, can be seen as a social and technoscientific form of engagement with possible societal stakeholders in nanotechnology such as sponsors, policy makers and consumers. This futurology exerts influence on the trajectories that nanoscale research takes. Visions of nanotechnology seem to be influenced by Science Fiction as they “draw equally from the inscription practices of scientific research and science fiction narration” (Milburn, 2002:269). Therefore, a nano-futurology seems to be vital for narrating NST. Often these visions are clad as 'long-term' projectives, but are also referred to in constant boundary work. Setting boundaries to demarcate nanoscale research from Science Fiction – one prominent example being the Drexler-Smalley debate – include the difficulty of re-stating but also revising many technological ideas voiced by nano-enthusiasts. This is an on-going negotiation process to retain governmental and commercial faith in the 'nano-future' without giving up too much of the novelty and the potential. The enabling and disruptive powers of nanotechnologies embody the notion of a positive and inevitable character of 'progress'.

Nano-enthusiasts write about technologies of the future, researchers are working on turning "*models* into *reality*" (Milburn, 2002:271, emphasis by author). Potentiality plays a significant role in narrating nanotechnological applications. The many small steps in their development are narrated into being the harbingers of a giant leap into the future. Most of what is presumed to render nanotechnologies enabling and disruptive remains to be developed, refined, comprehensively assessed and regulated. These are, in most cases, tasks realisable only in the medium and long term (The Royal Society *et al*, 2004). So far, little has been achieved compared to the grand or grim visions of nanotechnology. The gap is especially noticeable in the area of commercial applications (Johansson, 2003), where the greatest of hopes have been 'invested' (cf. Arnall, 2003:21), but today's available applications remain rather limited.

Norbert Jömann differentiates five stages of nanoscale research and applications, (1) being the most advanced and (5) being the most basic stage of development (2004:6).

(1) mass-production (computer hard discs, sun lotion, car tyres)
(2) introduction to the market (functional pigments, self-cleaning surfaces)
(3) prototypes (nano-tweezers, drug-targeting)
(4) development (ultra-fine filters, catalytic nanoparticles)
(5) basic research (biomimetic receptors, quantum computers)

They show that sophisticated nanomaterials and advanced applications of a more 'enabling' nature are still in the earlier three stages, whereas products made of nanoparticles being the result mainly of greater miniaturisation can be found in the upper two stages.

Whereas Science Fiction and NST seem to share terminology and visions – for example in using the prefix 'nano' as indicator for progress and novelty – most of nanoscale research is still engaged in developing and exploring approaches to controllably influence atoms and molecules. The step from Science Fiction to science facts, therefore, appears a long way off.

Attempts of nano-enthusiasts and lobbyists to negotiate nanoscale research as real science – while at the same time emphasising the disruptive promises of nanotechnologies – can be seen as a synchronic game with imaginations to retain support and faith of decision makers.

*The Construction of Narratives of Nanoscale Research*

Despite its contestations, NST can be understood as an entirely new emerging field, if we accept the following assumptions: (1) it incorporates two paradigms: biomimetics and mechanical engineering, (2) the 'futurology' of nanotechnology – regardless of its unlikely aspects – is a new approach to the world, (3) the emergence of technologies for visualising and modifying objects at the nanoscale has only recently opened up actual possibilities of working with atoms and molecules in a controllable and directed environment.

This paragraph is a result, and also part of, a nanotechnological narrative. It draws on sociological analyses, on a certain history of innovation and on the debate on NST. One of the most famous incidents – referred to by a significant part of the literature on NST as the starting point of scientific occupation with nanotechnology – is Richard Feynman's famous talk “There's Plenty of Room at the Bottom” at the California Institute of Technology in 1959. The physicist Feynman is often described as the first scientist to address the possibilities of manufacturing at the atomic scale:

> “Consider the possibilities that we too can make a thing very small which does what we want – that we can manufacture an object that manoeuvres at that level.” (Feynman, 1959, at <http://www.zyvex.com>)

However, it can be argued that Feynman's talk represents only the basis for the popularised understanding of NST's recent development, which I call the 'futurist' strand. Or, as Milburn puts it, his talk may be “resurrected over and over again as a cheap way of garnering scientific authority” (2002:277). For an 'evolutionary' understanding of nanotechnology which sees traditional disciplines as progressing towards an increasingly smaller scale, Feynman may have simply voiced ideas and drawn wider attention to the field.

*Towards a Revolution: The 'Futurist' Narrative*

Both Feynman's visionary speech and John von Neumann's reflections of the purely logical possibility of self-reproducting automata have inspired Eric Drexler (Bueno, 2004a) to develop ideas of nanotechnologies in "Engines of Creation" in 1986, the first non-technical book on NST. This book has had a considerable impact on the public perception (Jones, 2004:3) of nanotechnology as well as on its funding. Critical voices see it as the source of a 'nanomania' (Sims Bainbridge, 2004:1146), gripping stakeholders in a kind of visionary social movement. And indeed, the 'futuristic' approach to NST, dubbed the 'radical view' by Wood *et al* (2003:25), combines utopian and dystopian visions of a 'nano-world' and projects a revolutionary, seemingly unavoidable development. Although the borders between what has already been realised in nanotechnology and what might become possible sometime in the future blur at times, 'futurists' have made the attempt to demarcate nanoscale research from Science Fiction. Some of Drexler's most prominent visions, such as the self-replicating 'nano-assembler' (1990) and 'molecular nanotechnology' (1995:7) belong to a range of ideas now widely regarded as Science Fiction. For a short period of time, his idea of molecular engineering had left quite an impact on nanotechnology in the natural sciences (for example Bhushan, 2004; Freitas, 1999), rendering Drexler somewhat of a 'guru' (Johansson, 2003:4). This influence can still be traced in societal and social scientific debates around the potential of nanotechnologies.

The viability of 'nano-assemblers' as basic manufacturing units in nanotechnology has been challenged in the Drexler-Smalley debate. This discourse has become an integral, if by physical scientists not necessarily widely received, part of the perception of NST. The difficulty of human-constructed 'nano-assemblers' has been exemplified by the scientist Richard E. Smalley in the dilemma of 'fat and sticky fingers' (2001:76), an interesting example of boundary work to determine what NST can do and what it cannot do within the scientific paradigmatic discourse. This scientific debate has been taken further by suggestions that a more biological approach might improve its viability (Whitesides, 2001:83). These competing ideas reflect the different epistemological approaches to the nanoscale and technological viability maintained by the participating academic disciplines. It also supports the notion of the highly contested nature of narratives of NST.

The 'futurology' of a Drexlerian NST is not only confined to technological and commercial aspects, but extends to envisage a 'social revolution' (Pergamit and Peterson as cited in Arnall, 2003:32), which will have an impact on all aspects of life and might substantially change social categories. This aspect has been taken up by social science and ethics to enquire into future possibilities and their societal effects (cf. Johansson, 2003:6; Joy, 2000; Jömann, 2004:80ff). This futurology has given rise to diverse technology assessment approaches; specific sub-fields like nanotoxicology (ESF, 2005:21); and considerations of how NST is communicated and what role ethics play in the assessment of NST (Rehmann-Sutter, n.d.; Rehmann-Sutter and Leach Scully, forthcoming).

As I have mentioned before, availability of public funding has been a major contributor to the proliferation of the prefix 'nano' and nanoscale research. Policy makers are supporting NST because of its economic promises (Johansson, 2003:5). US institutions such as the National Nanotechnology Initiative (NNI), the Institute for Molecular Manufacturing and the Foresight Institute are part of the 'dream-machine' that energises the funding of nano-labelled research projects. Their publications and web pages propagate a steady progress towards the realisation of highly advanced nanotechnologies. Indeed, a vicious circle appears to have been created, in which funding bodies' expectations, started and fostered by 'nano-enthusiasts' and visionaries have led to great investments, which in turn have themselves increased and directed 'nano' research. However, to maintain a scientific understanding of NST, many scientists prefer not to make high-flying promises. At the same time, they do not discourage visions of a nano-revolution (Jones, 2004:5), probably to retain the abundant funding opportunities.

*Incremental Development: The 'Evolutionist' Narrative*

Whilst the 'futuristic' strand relies on NST 'heroes' and their visions, the 'evolutionist' narrative holds that NST takes advantage of incremental development processes in established disciplines (Jones, 2004:7; Toumey, 2004:98). Top-down technologies such as lithography and etching have been in use at least since the 19th century, and have been refined to create smaller and smaller functional units today. General scientific innovation has thus led to the construction of  theories and invention of technologies and methods, all of which enable the visualisation and influence of objects at the nanoscale. Especially the inventions in microscopy during the 1980s – the STM and the AFM (see *Chronology of NST*) – have provided the technological backbone for the emergence of nanoscale research in making the nanoscale discoverable (Jones, 2004:16,28,31). Reasons of costs and expertise, however, had kept images of atoms and molecules rare. Although electron microscopy has existed since the middle of the 20th century, only the advantages of the AFM – easy to use and cost-efficient – have allowed wider research 'access' to the scale of atoms.

A second branch of technological drive towards nanotechnologies is the miniaturisation in the microelectronics industry (Siegel *et al*, 1999:241; Williams and Kuekes, 2001:104). Smaller semiconductors, circuitry, microelectro-mechanical systems (MEMS, for example optical switches) are the aims of the microelectronics industry, aspiring to create nanoelectro-mechanical systems (NEMS) in the area of nanofluidics. For this, chemical expertise and crossdisciplinary collaboration is needed. To achieve an even greater miniaturisation new technologies have to be devised – nanotechnologies (Arnall, 2003:33f). This narrative's perspective is characterised by a "cautious approach" (Wood *et al*, 2003:27) to NST: what is really possible now and in the nearer future (Jones, 2004:49f), but also by the necessity of incremental development towards nanotechnologies, thus by the inclusion of nanoscale research in the wider disciplinary evolution. This evolution of technologies in physics, chemistry, engineering sciences and molecular biology towards smaller scales are another on-going process of miniaturisation. Top-down techniques play a significant role in the cautious evolution of nanotechnologies. Instead of building artificial biological systems, nanotechnologies attempt to harness existing biological systems, for example by applying soft lithography using rubber stamps and molecule-thin inks (Jones, 2004:50f). Scientists, constructing this understanding of nanotechnology, apparently conduct research in the ways of their disciplinary frameworks and across disciplines when necessary, accept the label of 'nano' as a funding opportunity and try to avoid making overly visionary promises (Toumey, 2004:98).

*Risk and Technology Assessment as Part of Narrating NST*

Future nanotechnologies may be environmentally friendly, even provide ways to tackle current issues of environmental pollution. Today's top-down nanotechnologies, on the other hand, are ecologically problematic (Jones, 2004:46ff): wet etching and lithography require high energy input and the use of toxic solvents. What kind of side effects on the environment will accompany the application of these top-down techniques; how high is the probability that nanotechnologies can become less pollutant?

Technology assessment addresses such issues and many more. Assessing technologies – their risks and their probable benefits – is part of 'responsible innovation' (Rip, 2005), which acknowledges and includes “social aspects [and questions of] desirability and acceptability” (*ibid.*) in the process of technology development. Anticipating and evaluating the probable impact of an emerging technology and thus gaining the opportunity to affect the trajectory of innovation includes, among many others, questions of motivation and possible trajectories of innovation (cf. Bruce, 2005), and potential applications (including 'dual use'). In the case of NST, these issues are being discussed while technologies are in different stages of development, and while the possible scope of medium and long term nanotechnologies is still uncertain. Therefore, technology assessment plays a vital role in constructing a narrative of nanotechnologies: assessment processes (1) formulate opinions and (2) influence trajectories by voicing recommendations, (3) include a range of stakeholders and (4) have effects on decisions concerning funding.

Nanoscale research takes place in the context of Mode-2 knowledge production. Research, the negotiation of trajectories, debates on understanding NST, and the assessment of possibilities span sciences and technologies whilst transgressing into the societal forum; mandates of progress are challenged or not applicable any more (Rip, 2005). Technology assessment needs to remain open in its outcomes to avoid generalisations and unnecessary blockade of research. The qualities attributed to nanotechnologies imply that there is a wide range of groups with vested interests in both the development of NST as well as its rather critical assessment. As with biotechnology, nanotechnology is debated in physical and social sciences as well as by policy-makers and non-governmental organisations (NGOs) or interest groups. Participation of the latter two has become an integral aspect of NST. That notion is supported by certain requirements for funding, at least in the US, which demand a small amount of funds spent on the consideration of ELSA in the innovation process. Indeed, in as much as GMO fared poorly in both gaining public trust and in rigorously assessing potential technology before its application, has NST become the focus of analysis. Arguable, the debates on biotechnologies and genomics might even be included in the narrative of nanotechnologies.

Technology assessment has become a key task of non-governmental networks and interest groups, as NST-studies by Greenpeace (Arnall, 2003) and the ETC Group (2003) document.

Institutions such as the European Network of Excellence Nano-2-Life, the Center for Responsible Nanotechnology (CRNANO) and the Meridian Institute in the USA are dedicated to the evaluation of aspects in NST. Their reports are directed at the public and policy-makers, sometimes also at decision-makers in the scientific community. Although a low awareness of nanotechnologies seems to prevail in the wider public (The Royal Society *et al*, 2004:59ff), terminology from NST increasingly enters the public domain, for example in life style consumable or household product descriptions and in media reports. The more information is available the more critical is public scepticism towards potential nanotechnologies (cf. Kearnes *et al*, 2006). Public participation in technology innovation can take place via technology selection processes (Rip, 2005), very similar to consumer choices in economical contexts.

*Reproducing NST: Academic Education in Nanoscale Research*

Drexler claims that he was among the first researchers to receive a Ph.D. in Molecular Nanotechnology from the Massachusetts Institute of Technology (MIT) in 1991, itself one of the first degrees in NST (Homepage of Eric Drexler).

Indeed, existing and emerging under- and postgraduate degree programmes with a focus on nanotechnologies seem part of the institutionalisation process of NST in academic science. The reproduction mechanisms of a research field are a signifier to its firmer establishment, in this case as a specialisation somehow at the borders of established science programmes, yet drawing very much from these. The institutionalisation of education provides a claim to being acknowledged as a continuous and novel research field. Apparently, a two-level education is being shaped. Scientists feel that a more profound scientific education in graduate schools, especially to train 'nanoscientists', is as much necessary as the exposure of undergraduate engineers to science (Fonash, 2001:175) and the training of engineers on the use of a diverse range of nanotechnologies, enabling them to transfer these to commercial applications (Whitesides and Love, 2001:137). Collaborative research between those is the basis for NST research. Consequentially, a shift to interdisciplinary education would be required.

Apart from academic programmes on NST inter-institutional training is offered by 'cross-path'-institutions combining academia, industry and governmental agencies. A recent example of interdisciplinary training in biology, chemistry and physics for nanoscience and nanotechnology is the “European School on Nanosciences and Nanotechnologies” in Grenoble, France, which offered courses over the period of three years (2004-2006) to junior researchers and engineers in the field.

*Multi-, Inter- and Transdisciplinarity in NST*

It is difficult to speak of the disciplinarity of NST when the different concepts remain unchallenged and are used interchangeably by scientists of any persuasion. However, it becomes apparent that interdisciplinarity in NST, first of all, seems to be politically aspired. The expected benefits of interdisciplinary collaboration refer to greater novelty and greater possibilities in the – economically feasible – outcomes of research. The US-American National Nanotechnology Initiative (NNI), with Mihail Roco as its prominent spokesman, has rendered interdisciplinarity as a core characteristic of nanoscale research. Schummer suggests that “nanoscale has become increasingly driven by social policy” (2004b:426) in that many funding programmes expect inter- or even transdisciplinarity without specifying what these concepts stand for. He challenges this attitude by asking what kind of interdisciplinarity is actually desirable and why (*ibid.*:462). This is a fundamental issue in determining the nature of NST: is the field multi-, inter- or transdisciplinary? And what do these concepts mean in practice? Transdisciplinarity is generally not described as a current or necessary feature of nanoscale research in much of the literature. However, in conjunction with the literature on the knowledge society and Mode 2 knowledge production, transdisciplinarity does seem to be a feature of NST in regard to at least one aspect: the focus on practical problem-addressing and solving. Nevertheless, in this section I focus on multi- and interdisciplinarity as the two most commonly referred to concepts in regard to NST.

A possible understanding of the differences between these concepts is given by Van den Besselaar and Heimeriks (in Morillo *et al*, 2003:1237), one which relies upon the level of interaction and is compatible to the concepts of 'trading zones' and 'boundary objects'. I have adopted this *interactional* approach for the following paragraphs, but expand on a slightly adapted conceptualisation of disciplinarities in chapter 7.

Although interdisciplinary is often seen as inherent or necessary for research in NST (for example Arnall, 2003; Siegel *et al*, 1999; Wood *et al*, 2003), nanoscale research is also analysed as being a multidisciplinary field. The reasons for different opinions on this may certainly lie within the missing theory of interdisciplinarity (Schmidt, 2004). Using a bibliographic method, Schummer evaluates the level of interdisciplinarity in NST as being not much higher than in established sciences (2004b:446), indeed relations and interactions seem “more scattered and less selective” (*ibid.*:448). A similar understanding is applied by the European Science Foundation in regard to nanomedicine, a major focus in nanobiotechnology. In their 2005-report, the perception of nanomedicine is “clearly multidisciplinary [as it] builds on the existing expertise in a large number of different scientific fields” (ESF, 2005:10).

Arguably, the image of nanoscale research being multi- or interdisciplinary is strongly influenced by the *determination* to make NST an interdisciplinary research field. In order to theoretically further this issue, a common understanding for these concepts is necessary. Interactional collaboration between researchers from different epistemological backgrounds are required independently from such a debate. Otherwise, innovative research in NST will hardly be possible. Bueno suggests to develop a 'simplified language' (2004a:103), which will not be able to integrate epistemologies but will be sufficient for communication, possibly fostering integrative processes. Gorman *et al* (2004) describe the field of NST as being a single huge trading zone by nature. Both views set the conceptual basis for nanoscale research evolving towards interdisciplinarity. An example for a boundary object in the trading zone of NST is the common goal to build controllable nanostructures and nano-objects, but with different applications in different participating fields. Scale and general intent are common to the field, as should best be terminology and understandings of the end products, too. The differences lay within the range of technologies applied towards this goal.

Should the trading zone support integrative collaboration, researchers in nanoscale research, coming from many different contributing sciences, may experience “problems of identity and loyalty” (Star and Griesemer, 1989:411) as 'marginal people' between social worlds – or sciences. In a truly transdisciplinary field, this may lead to the formation of “a new social world composed of others like themselves” (*ibid.*:412), that is an independent discipline – regardless of the type of paradigm(s) it may adhere to.

## 5 Summary

In this chapter I have concentrated on social scientific literature on Nanoscale Science and Technology from Europe and North America. Therefore, this review is probably culturally biased, which seems appropriate in the context of a UK and Europe-based study. The list of references may suggest that I have deliberately omitted sources from, for example, Japan, South Korea, Taiwan, or Russia, all hosting quite active nanoscale research communities. However, publications on *social and ethical considerations* of the research field seem to be almost non-existent from these countries, or they are not published in Euro-American journals and anthologies. It would be interesting to see why this is so. One strand of enquiry into possibly why ELSA studies are of little importance in Japan or Taiwan could be the experiences with GM foods in East Asia. In contrast, the *technological* literature I have relied upon does refer to publications by researchers at East Asian universities and research centres.

Over the course of my literature review, I have not only widened my insights in NST, but also adapted my terminology. 'Self-assembly', 'wet/dry interface' and 'biomimetics', among other concepts, have entered my (informed) vocabulary just as much as sociological concepts: 'co-production', 'technoscience' and 'Mode 2 knowledge production'. Nanotechnoscience as a critical concept in the understanding of the field has merged the readings on SST, STS and NST. At the same time, I have adapted my terminology to refer to the comprehensive field of nanoscale research as 'Nanoscale Science and Technology' instead of 'nanotechnology' to emphasise the expanded, diverse and technoscientific connotations of the terming.

My theoretical framework is based on the aim of SST to learn about the social side of science, and translates into my aim to explore how NST is constructed by scientists. The practical approach of STS is reflected in examining the practice of knowledge and technology production in science, and in identifying impacts that NST might have on academic science. SST and STS complement each other in improving the understanding of knowledge production processes (cf. Webster, 2007b:459). One of the main STS concepts I rely on is technoscience: a conglomerate of applied science, technology, societal interests and problem-orientation. I follow and expand the understanding of NST as a technoscience in the context of an increasing practice of Mode 2-style knowledge production: across disciplinary and institutional boundaries, with a focus on practicality in research outlooks. The main dimension in identifying how research is conducted and what impacts this might have, is the organisation of knowledge and its production (*disciplinarity*). My main analytical elements are *collaboration* and *identity*, but also the focus on *academic* science practice. The analysis chapters in this thesis can be roughly divided along these interconnected elements.

In the next chapter, I look at the methodological framework, methods and conduct of my research project.

# Chapter 3: Interpreting Science and Technology



## 1 Introduction

In the previous chapter I elaborated on the debates of the object of my research, NST, and developed the framework of my research. I laid out the basic concepts I employ in this analysis. In this chapter of my thesis I provide an overview of the methodological approach and a brief account on my research practice.

As I concluded in the previous chapter, I draw on the fields of SST and STS for my research. They have supplied techniques, concepts and guidance in exploring and analysing further narratives of NST. The concepts, in particular, have provided starting points for my analysis. In my research I revise understandings and concepts to expand the analysis of contemporary knowledge production in academia, as I present in chapters 4 – 7.

In the following sections I provide an overview of my epistemology, the methodology and the research design applied in my project and my rationale for so doing. Furthermore, I shall briefly reflect on my choices regarding the sample of respondents and observation occasions. I then give an account of my fieldwork in interviews and observations, followed by ethical considerations that have emerged. Finally, I provide a brief section on the process of my analysis including issues of a practical nature.

## 2 Brief Epistemology

My background in pedagogy influenced my choice of the initial main research question: to explore the nature of *collaboration* in contemporary Nanoscale Science and Technology as a way to understand the nature of NST itself. Collaboration as a space of interaction has seemed the appropriate approach to an emergent field of science and technology. Part of the exploration of collaboration in a novel field is to examine its wider practice. In that regard, disciplinarity has emerged as a vital dimension from the analysis of NST narratives, particularly in the notion of crossdisciplinary collaboration being foundational in NST research practice. However, I have decided to also examine the structural dimension of disciplinarity as an institutional element during my analysis. Thus, I examine both practice and structure of NST in the analysis of its disciplinarity: how do researchers construct research practice, and what is the institutional nature of NST?

Furthermore, in the review of debates around NST, especially scientific debates attempting to demarcate science from science fiction (boundary work), identity and collaboration have emerged as two intersecting elements in research practice. In summary, I have expanded my research question over the course of the study: from trying to understand the collaborative nature of NST to exploring the nature of practice and disciplinarity in NST in the context of contemporary academic science.

The social world consists of interconnected agents, agendas, agencies and activities, which are constituted in and contribute to the experience of social life and the institutionalisation of structures of the social world (cf. Harré, 1998:41ff). The realm of science is a distinct part of that social world where specific interests and practices intersect and constitute specific scientific and administrative knowledge production processes. However, the way knowledge is *produced* and the way it is *understood* vary greatly in themselves as activities, between social realms, such as society and science, and within substructures of each realm. For example: differences between scientific disciplines and their epistemologies, or academic and industrial research. The “ways of knowing”, as Harris (2007:4) suggests, are situated and constantly renegotiated. These ways refer to the diffusion of knowledge that is (1) created and (2) experienced *or* learned as a 'fact'. The debates around NST try to dissect factualised knowledge, to open up the 'black box' NST. My study aims to contribute to this opening up by looking at how knowledge is produced, by reflecting on the experiences of scientists in this field. The 'facts' then become interpretations, a way of knowing needed to be acknowledged in attempts to lay open the presuppositions of any analysis (cf. May, 2001:28–37).

The interpretative nature of my qualitative research is reflected in my aims to understand how scientists working in nanoscale research construct, interpret and reconstruct their research realities. This can be perceived as a co-construction of research practice with knowledge application, and provides links to the 'why' of the particular construction of practice. However, this makes apparent the normative (in the literature review) and empirical (in fieldwork) approaches to science and technology with the aim to gain a social scientific understanding. Therefore, in my analysis I draw on social scientific theoretical frameworks, methods and concepts. This approach is similar to Dreyfus and Rabinow's 'interpretive analytics' (May, 2004:16) in attempting to merge the subjectivity of social research with the empiricism that introduces evidence to contemporary social science (cf. *ibid*:15f, 40–43). Social science then is more than descriptive or normative, it provides critical explanatory models, which can provide means for policy development, even for practice modulation (change) (cf. Bloor, 2004:320f). In my analysis, however, the explanatory aspect is stronger. The aspect of power of definition, or ability to influence, is reflected indirectly in examining relationships in scientific collaboration and the disciplinary structure and practice of NST as a research field.

In summary, my study can be compared to exploring a land so distinctly different to one's own as “a stranger in strange land(s)” as Webster put it (2007b:463). I develop an understanding of science practice by using and adapting social scientific (familiar) concepts. Choosing a qualitative methodology allows me to explore attitudes and individual perspectives on scientific practice and culture. However, qualitative research increases the need and difficulty to render findings robust as they are interpretative and cannot be quantifiably representative for the overall population of NST scientists. At the same time, my findings of a specific population of NST need to be generalisable for an extrapolation on structure and practice of new and emergent science and technology fields and academic science practice in these.

## 3 Methodology: Case Study

My decision to conduct a case study of NST in the North-East of England was influenced by two main factors. Methodologically, the rationale has been to conduct manageable research by examining a 'snap-shot' of wider debates. Bearing in mind general ideas and notions from the wider debates around NST and contemporary academic science, a case study provides the means for an in-depth examination of scripts, motivations, agencies and activities in a smaller context, which remains comparable to the larger context (cf. George and Bennett, 2004:19ff). The methodological rationale connects to the empirical one.

Empirically, the rationale originates from the richness of references to and labels of nanoscale science and technology in the research community of the North-East: research organisations and events, funding and supporting programmes, degree programmes and references in the self-description of researchers. For my case study I expected to see a strong interconnectivity between participants in their work and its context, but also differences. Especially so in how this shared context of the NST micro-cosmos in the North-East translates into individual reflections on their experiences in and understandings of NST. Although my case study focuses on three universities in the North-East, I include a wider pan-European perspective through my literature review, observations, and interviews and conversations. For supplementing research findings it proved to be very helpful that academics and institutions at Newcastle University had been affiliated with the European Network of Excellence Nano-2-Life. This connection provided many insightful opportunities to attend events for observations and thus to tie in my case study into the wider NST research community. By utilising opportunities of attending events that reached out to the North-East region and beyond, I have been able to embed the local character of my study into the European context in spite of being focused on Newcastle University and including a very small number of respondents from Durham and Northumbria Universities.

However, a case study must always be content with providing only a section of the greater field of enquiry, which links directly to the empirical rationale of being biased in choice, scope and focus of the case study population (cf. George and Bennett, 2004:22f). There is still a significant focus on the UK situation in my work, and a part of the UK at that, where regional idiosyncrasies have to be expected. This has become quite apparent in my respondents' accounts contributing to understanding the politics of science in the North-East. Researchers' accounts on previous NST-funding allocation, trajectories of institutionalisations, and the slightly scattered practice of nanoscale research at the universities, all contribute to a picture of NST in the North-East. At the same time, the literature review and talks with scientists and social scientists in the field indicate that although these regional idiosyncrasies exist they are connected to the wider narratives of NST and the emergence of other novel research fields in the context of adapting knowledge and technology production modes.

Therefore, extrapolation towards a generalisation of this case study for the wider NST field is possible (cf. Stake, 2000:23). At the same time, this case study and its connectivity to the wider case of NST is context-dependent: the context of European science policy and the nature of contemporary academic science. Nevertheless, it allows for a historical comparison if necessary owing to the themes of my case study being generic to science and its practice: identity, collaboration, disciplinarity (see *Research Design* in this chapter). In regard to extrapolating my findings from the case study to the wider field of science studies, I propose that a combination of (1) generalising within a specific context and (2) the continuous 'transferability' between the specific and the wider contexts (cf. Lincoln and Guba, 2000:36ff) allow for extrapolation beyond, first, the individual and, then, the combined accounts of the interviewees. The specific context for NST in the North-East can be NST in the framework of new and emergent science and technology fields, whereas the wider context, which benefits from a generalisability in a continuum, is contemporary academic science. This understanding of contextualisation is independent of the naturalist ethnographic model as criticised by Silverman (2006:98).

A prerequisite to constituting comparability and thus generalisation is to combine empirical data from individual interviews and observations, and also to reference these to the wider debates around the object of enquiry. I have integrated the case study findings in a framework that relies on disciplinarity. Both, the practical and the structural elements of disciplinarity are embedded in the debates, and thus narratives of NST as well as academic science in general resurface in the accounts of my interviewees. In an attempt of 'totalization' (Baszanger and Dodier, 2004:20ff), that is of (re)constructing a coherent whole of the data from my interviews and impressions from observations, I link the empirical data from my interviews with individual scientists to the overall narratives of NST that emerge in the analysis of scientists' accounts. These two, the specific data and the narratives, are entwined through the research themes of my study. This process of 'totalization' connects with generalisation through comparability (cf. George and Bennett, 2004:112f). Strong national and international collaborative elements emerge in the accounts of my interviewees and link the local to the national and beyond. Through the aspect of 'belonging' in my analysis of research identity, the connectivity to the wider academic science community is established as institutional scripts in science and science policy are more or less shared. Also, once again, the disciplinary dimension is overarching. In effect, the integration of my data is based on scientists' narratives.

In summary, this case study displays an *intrinsic* nature by portraying, acknowledging and embracing the idiosyncrasies of a specific example, that is NST in the North-East of England. However, it also has an *instrumental* nature in that I explore via this example a wider issue of academic science in Europe and North America. This, then, provides theoretical and empirical merit of this study (cf. Silverman, 2005:127f). Description, and explanation and extrapolation constitute this study, evidenced in my analysis along specific themes in the theoretical framework of contemporary science changes in Science and Technology Studies (STS). I reference 'Mode 2 knowledge production', 'technoscience' and 'hybridisation' of knowledge production in NST as well as 'co-production' and 'co-evolution' of scientific and societal interests, and I confront these concepts with empirical findings and contribute to the adaptation and modification of their understandings. However, although my study displays a rather strong theoretical framework, my analysis goes beyond the normative and provides explanatory insight as becomes apparent in later chapters.

## 4 Research Design: Aims and Questions

My main research aim has been to examine the nature of NST.
From the outset, the focus has been on collaboration as a central element in the analysis of research practice. This practice provides indicators as to how a research field is constructed, interpreted and reconstructed, thus to its nature. However, the focus on collaboration cannot be exclusive, but implies a range of intersecting dimensions. A structural approach to understanding collaboration lies in its organisation, or, to be more precise, in its disciplinary organisation. Disciplinarity features in contributing elements (the disciplines and their representatives) and in constituting elements (the type of interaction and its organisation) of collaboration. Both draw on institutional affiliations (for example as membership) and on research experience and specialisations of researchers. Subsequently, I have expanded my enquiry to include scientists' negotiation of their research identity. Therefore, the three main themes of my research are disciplinarity, collaboration and research identity. They provide both focus and guidance, and connectivity to the larger debates.

The nature of NST is embedded in the context of general academic science practice, both provide the larger context to my case study. Research into practice and disciplinarity of NST implies a wider impact study, or a second aim, namely to identify potential changes in the nature of academic science practice. These changes are implied but also discussed in the scientific and social scientific debates of NST, which share the notion of nanoscale research being a crossdisciplinary and boundary-transgressing emerging research field. Because of this focus on the transgression of disciplinary and institutional expertise, disciplinarity emerges as the 'scaffolding' on which the analysis of collaboration and identity negotiation can be developed.

A third aim lies in understanding how the social features in NST research practice. This connects directly to collaboration by exploring crossdisciplinary interaction as a social element to research practice. An understanding of the social aspects in science practice, in particular their influence on knowledge production, relies on extrapolation from scientists' views on non-academic or non-scientific aspects in their research experience. Cultural influences feature only on the side as I focus on institutional scripts in my study.

These aims and considerations translate into a range of research questions, which help to address the aims mentioned above of exploring the nature of NST.

- How do scientists, working at the nanoscale, perceive NST?
- What role does NST play in scientists' construction of their research identity?
- Does disciplinarity still feature in the construction of research identity? If so, how?
- What role does crossdisciplinary collaboration play for research in the field of NST?
- What kinds of disciplinarity feature in NST-collaboration?
- Is NST becoming a discipline in its own right?
- How do scientists perceive their research in regard to its uptake in society?

Two steps have rendered examining the nature of NST in my study viable: (1) defining the main aspects of its nature and thus focus on disciplinarity, collaboration and research identity (themes); and (2) devising corresponding research questions to address these themes in conjunction with other contributing factors such as the debates in NST and its narratives. Retrospectively, the themes and research questions developed during the literature analysis, and from personal interest in the notions of structuralist theories such as (neo-)institutionalism.

## 5 Methods: Interview and Observation

The three approaches I have applied in exploring NST are literature review and analysis, qualitative interviews, and sensitising participant-observations. As I rely on an initial literature review, which has informed my theoretical framework, and because of the combination of interviews and mixed observations, my study can be described as a 'small-scale' ethnography. The methods I used are influenced by ethnographic approaches. A 'full-scale' ethnography would have required to choose a case of a single research organisation and explore it in depth by immersing in the specific context, for example by visiting or staying in the laboratory (cf. Doubleday, 2007; Johansson, 2008). However, there are two reasons for why this approach would have been limiting. First, settling for one institution, instead of interviewing scientists in different institutional settings, would have limited my understanding of NST. However, my initial approach was a broad understanding of this field in order to be able to construct an understanding from the diversity of researchers and institutions. Second, a focused and inclusive ethnographic approach could have focused on interviewing and observing research activity in close connection to the laboratory bench. However, most (crossdisciplinary) collaboration does not take place at the lab-bench but in meetings and events outside the lab.

*Ethnographic Elements*

Although this study needs to be distinguished from 'full-scale' ethnographies, for example as considered by Baszanger and Dodier (2004) and by Silverman (2006), it does have ethnographic elements owing to the very nature of a case study as an exploratory and exemplary 'snap-shot'. I conducted observations not only during meetings where I was an outsider, but also during events where I was a participant due to the interdisciplinary nature of the event. I was, therefore, able to include participant-observations in my analysis. These observations were of a sensitising nature, providing me with ideas and notions that supported the data from my interviews and impressions garnered from the literature analysis.

Because of the exploratory and exemplary nature of my case study I had to be aware that my research focus could change throughout my fieldwork, despite following the three themes – disciplinarity, collaboration and research identity – from the outset, in adapting interests and letting the empirical input influence the theoretical outlook (cf. Fielding, 2001:148). The more interesting aspects of these themes and their interdependence became clearer with the progress of my data collection and pre-analysis. The ethnographic nature was limited, again, by the three theoretically induced themes structuring my fieldwork, and by the preference for interviews over observations.

*Applied Methods*

The literature review and analysis (chapter 2) was aimed mainly at social scientific literature, but I also included scientific introductory literature. The review provided me with scientific and social scientific understandings of the field of nanoscale research, and introduced me to the main debates around NST. At the same time, the literature helped me become acquainted with current debates on academic science practice and the relationship between science and society. Analysis of these debates helped me to identify key issues for and in NST and STS in order to develop an idea for the potential scope of my research (apart from the focus on collaboration), and guide my research approach.

Qualitative interviewing was the main source of data in my research. I planned semi-structured interviews to provide me with a number of personal narratives – twenty to twenty-five – of those seldom heard in the analysis of NST, the scientists spending the majority of their research lives in the lab and/or office. The qualitative approach, I hoped, would help to acquire first-hand insights into how researchers construct entities of science and how they experience research practice in NST (cf. Burgess, 1984; Silverman, 2005). My consideration of relying solely on interviews for my data collection raised a number of questions, which I elaborate on later in the section on *Method Development and Fieldwork*. The most significant two, however, were those of information density within and consistency between individual interviews. I had to be aware that respondents might not remember, decide not to communicate or even not have experiences relating to the content of my questions (cf May, 2001:128). I addressed the first if these possibilities by providing examples in each interview; the third I accepted as a further element to my analysis; and the second issue I could either accept, or extrapolate from other parts of the accounts.

I planned to attend observations in order to get acquainted with researchers on a less formal level, to localise potential interview partners, but also to get more or less first-hand evidence on one significant aspect of academic scientists' research practice: the interaction between scientists in their project meetings and networking events. As an additional bonus, attending events and conferences allowed me to get a better picture of the management and setting up of research interaction on a European level. The issue here was that I would be doing all observations and thus be influenced by my own interests, assumptions and previous reading. This would increase the subjectivity of my study as I as the researcher was the “main instrument of social investigation” (Burgess, 1984:79). At the same time, the issue of subjectivity is characteristic for research, but can be negotiated by contextualising the data analysis through references to the theoretical framework, and to other specific or more general contexts.

Two of my research approaches, and I further detail the processes of interviews and observations below, are empirical and qualitative. Their main utility is to explore the experiences and understandings of scientists in their everyday research practice, but also to extrapolate from these accounts (in coordination with the literature analysis) an understanding of the disciplinary elements of NST. There have been quantitative studies on NST as I have shown in the previous chapter, but in my aim to include the perception of scientists themselves, such an approach would be lacking. Both interviews and observations allow for relatively non-predetermined data. However, research design and implementation are influenced by personal expectations and my literature analysis. Interpretation and analysis take place from the outset.

*Rejected Methods*

In the development of my study and fieldwork, I considered collecting further data through focus groups and respondent diaries, but rejected these for several reasons.

Focus groups can help produce data by setting a forum for exchanges between scientists, thus allowing to compare perceptions and negotiations of ideas. They are particularly helpful in the preparation of interviews to garner some of the perceived major issues of the sample and field of study (cf. Cronin, 2001:168). However, four arguments against proceeding with this idea emerged during the preparations for my fieldwork: (1) time/availability, (2) seniority of interview partners, (3) the social scientific nature of a scientists' focus group, and (4) the issue of confidentiality.

In preparation of my fieldwork, it often proved difficult to negotiate access to potential respondents owing to time restrictions. Focus groups generally take more organisational effort in bringing together a significant number of participants – five to eight – to meet up at any one point. Therefore, it would have been highly unlikely to form focus groups of scientists. The second counter argument lies at the heart of the method of a focus group: senior researchers might have felt threatened or challenged in regard to their position and esteem in a focus-group format, whereas less senior researchers might have felt inhibited to discuss freely. The third argument connects to this. I expected scientists to be reluctant to discuss with research colleagues scientific or non-scientific issues in a forum set by a social scientist, and a junior scientist at that. Also connecting to the second argument is the matter of confidentiality. The North-East research community is rather small and intimate, being able to make statements as confidently or feeling as comfortable as in face-to-face interviews might have been more or less impossible. Of course, I could have arranged for the focus group to be a rather informal gathering, but still the chances of getting senior researches to attend would have been small.

Respondent diaries as *solicited* documents were the second method that I considered to be non-viable in this research setting. A colleague suggested to ask respondents to keep a journal or diary over the course of a few weeks to see how they observe incidents of collaboration the day these happen. Such 'private papers' (Macdonald, 2001:199f) can contain primary data of personal observations, decisions and interpretations. Via their keepers' style, particularly lexical choices, semiotics and emphasis on what records to be made, they can provide a very rich and elaborate set of data for the analysis, especially in the case of allowing keepers to decide on their own the specifics of what to note (Burgess, 1984:125,129f). Thus, data might have been preserved, which in an interview setting might not be easily recalled or formulated. It is possible that this might have had an impact on my outlook and the analysis process. However, three issues rendered solicited documents difficult: (1) time, (2) viability and (3) the matter of seniority. Would researchers have and take the time to keep the diary as regularly as requested (and required for the analysis)? It is very likely that to do so is not feasible 'on the job'. Instead, this method would have implied an intrusion into scientists' private lives, reflecting on work after work hours. Even more important is the issue of potential loss of data, for example by respondents deciding not to keep a journal, or keeping it on an irregular basis. Connected to this is the question whether my respondents, most of them more senior than I as the researcher, would agree to keep a diary on my request, and in how far they would feel free to record their observations and discuss these, especially those in a management position.

Obviously, both methods have their advantages, especially in combination with face-to-face interviews and/or observations in order to scrutinise written with verbal accounts and practice as perceived through my eyes as the researcher. However, the disadvantages in this case have weighed more heavily by rendering the implementation of these methods difficult.

*Theoretical Sampling*

Retrospectively, I recognise problems of sampling that at the point of approaching researchers did not seem pressing, when I was most concerned with the combination of time management, access, approach technique and relevance to my themes. Differences in age, gender, seniority, epistemology and so forth among my respondents are aspects that I became aware of already during my fieldwork, or during the writing up stage in my analysis.

My sampling method is a combination of several approaches. It comprises two major aspects, the first being what Honigmann calls 'non-probability sampling' (1982:79). This non-probability sampling is constituted by *judgement* and *opportunistic* sampling (*ibid*:80). Opportunistic sampling provided the vantage point for my scoping and piloting interviews. My first interview partners were social scientists and ethicists active in the field of NST. They participated in the European Network of Excellence Nano-2-Life. I was able to approach them through my supervisor's involvement in the same network. In these conversations I was able to garner further information for preparing my data collection with scientists. Also, the first small number of scientists in my case study were connected to Nano-2-Life. Opportunity has played a strong role in my sampling process, supported by contacts made through events organised by Nano-2-Life.

However, *opportunistic* sampling also played a significant role later on in my fieldwork, once I started to interview several scientists. Respondents' recommendations of colleagues as potential interview partners, or of NST-events for observations, helped considerably in gaining access to further fieldwork opportunities. Nevertheless, there were some scientists who I could not get access to despite recommendations, and in retrospect I believe these had to do not just with a strong burden of workload, but in some cases also with several issues of institutional politics (see *Ethical Issues* in this chapter).

Contributing to my continued sampling were understandings and insights gathered from the ongoing debate on the scientific and social natures of NST. The main lines of enquiry here refer to what might constitute NST research, and, thus, what might be a relevant scientific specialisation or expertise. This, then, influenced my aspired mix of respondents, as did my intent to include researchers from all career stages in regard to the social, that is interactive-collaborative nature of NST.

The second, and later, element of my sampling method was *theoretical* sampling in the context of *interactive* sampling (cf. Burgess, 1982:75f). I chose sites and respondents in reference to my theoretical framework, and thus in 'interaction' with my emerging research themes. This has had consequences for the overall nature of my study. It is exploratory and opens up opportunities for further studies of NST and other technoscientific fields, because the sampling of further cases and of respondents is implied (cf. *ibid*:76).

I contend that for a theoretically influenced sampling the *judgement* variety has to come first, as I approached specific scientists chosen according to the above methodological type. Therefore, my respondents came from a number of disciplines and subdisciplines in the natural and physical sciences, from engineering and, later, also from the clinical sciences. They research matter and effects at the nanoscale (up to micro-scale) and their applications in diverse contexts within an academic or academic-clinical or academic-industrial setting. In my preliminary selection of potential respondents I included scientists at all career stages, from doctoral candidates to senior managerial scientists, with institutional affiliations to organisations that include 'nano' in their descriptions or in their research portfolio. I also looked out for references to NST as constituting an aspect in scientists' research, in publication lists and among esteem factors such as editorial work, refereeing, or academic degrees. Therefore, my sampling was *purposive*, *opportunistic* and *theoretically* guided. I focused my choice of researchers on those whose participation in my fieldwork would contribute to my theme-guided research questions, but at the same time I allowed a wide approach to the sample as my study included a strong exploratory element (cf. Silverman, 2005:131f). An example for this is the broad approach taken to what NST is constituted by or what it means to scientists. I have sought to understand the nature of NST, how it is constructed and perceived by its protagonists, in this case scientists. A strong, and thus limiting, definition ignores a significant number of people that find themselves doing what they might describe as 'nanotechnological' or 'nanoscientific' research, but would not necessarily embrace the terms 'nanotechnology' or 'nanoscience' as their scientific or disciplinary background. This distancing, as I point out in the following chapters, is a significant aspect of the nature of NST. Fellow doctoral candidates at European universities have chosen to narrow down their definition of nanotechnology or nanoscientific research for their respective projects. They did so with good reason within the context of their enquiries, obtaining a strong focus for their sampling of respondents and cases, and for the overall thrust of their research questions. For my research, the choice I made has helped to approach a range of diverse scientists, with very different disciplinary backgrounds and specialisations, and, despite this being a regional case study, with good research connections to the European research community. All of these contribute in some way or another to the narratives of NST by referring to 'nano' in similar or different ways.

## 6 Fieldwork

I conducted twenty-five interviews from November 2006 until May 2007 (four 'sensitising' and twenty-one data interviews), and attended five NST-events in 2006 and 2007.

In preparation of my fieldwork, consisting of twenty-one *data* interviews with scientists, I drafted a general overview of organisations involved or connected to NST in the North-East of England. This overview (Figure 1, p.68) is by no means exhaustive. However, it provides an idea of the vast number and diversity of NST-organisations and implied interests in the field (commercial, facilitation, advice, funding etc.). The map draws on institutional information found on the internet, and on information gathered in attending NST-events such as NanoMed 2006, a networking event for canvassing ideas and interests in nanomedicine in the North-East. Attending the event not only made me aware of diverse projects and stakeholders, but also allowed me to start considering respondents for my fieldwork.

Initially, I considered to include scientists from commercial businesses in my interviewing process, but then decided to focus on the academic population, and thus on academia as the institutional context of my study. During my fieldwork I became aware of the seemingly regular exchange of researchers between academia and industry, and the sometimes dual involvement of scientists in both academic research and commercial businesses, or in commercially viable academic research.

**Figure 1: NST Spaces in the North-East of England in 2006**

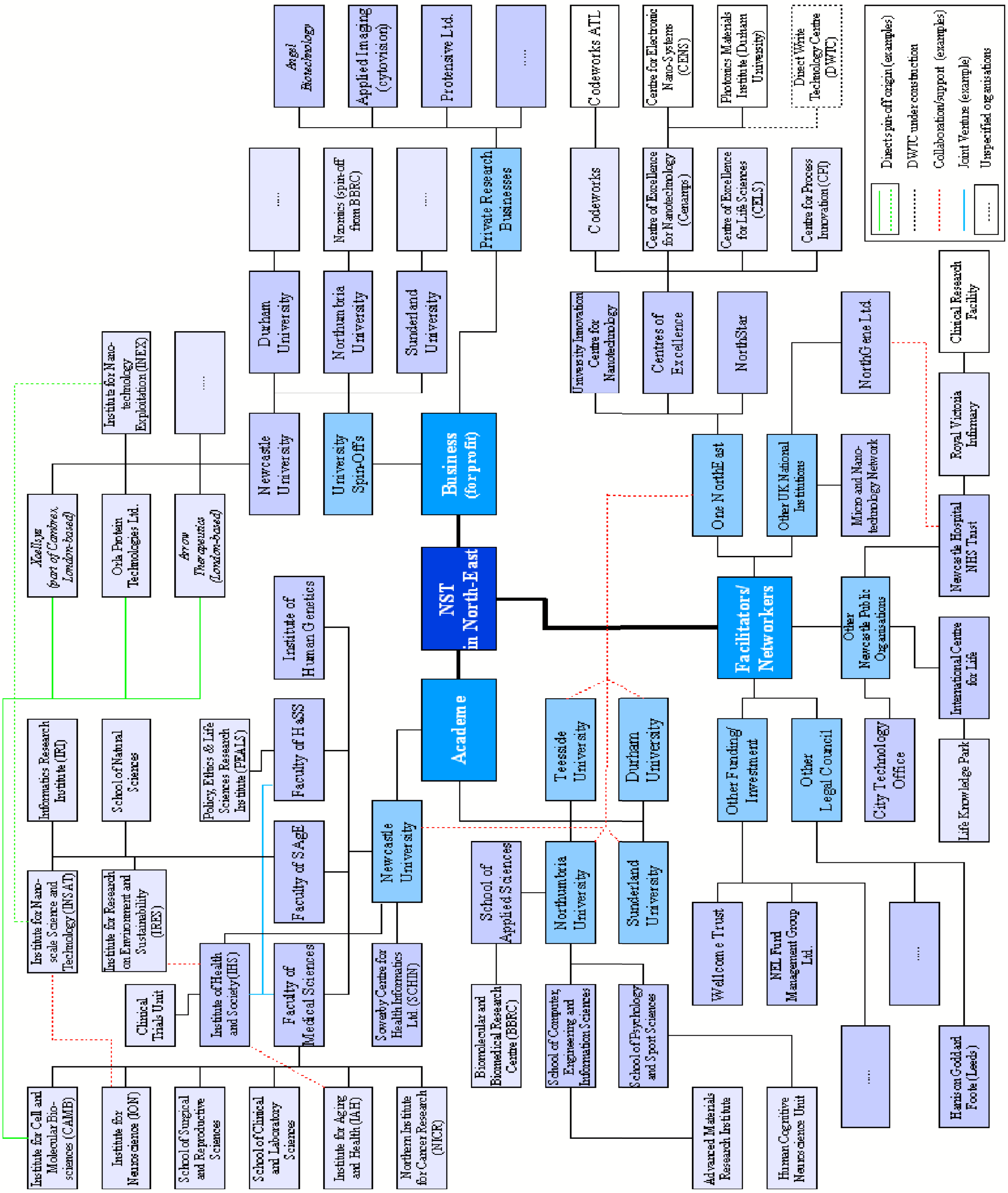


Figure 1 gives an impression of how I initially explored the landscape of NST in the North-East, a way of identifying and mapping organisations and their connections as well as activities. This map does not represent the direct sources for my respondents nor does it provide an overview of the disciplinary affiliations of my respondents. I decided not to provide such an overview for two reasons: (1) I wanted to assure as much anonymity as possible for my respondents from this small community of researchers engaged with NST in the North-East. (2) One of my aims was to understand the disciplinary nature of NST. Therefore, classifying respondents according to broad disciplinary categories would have been counter-productive to exploring disciplinarity in NST practice. On the other hand, an account of the very specific disciplinary specialisations of participating scientists would have resulted in a complicated and little informative overview. However, I did seek and talk with respondents from the broad range of disciplinary institutions and crossdisciplinary specialisations contributing to the field of NST.

*Attending NST-Events as Observations*

Observations provided me with 'real-time' background to my interviews and the literature review. I visited NST-events at irregular intervals. In 2006, I attended an idea-canvassing bi-national science networking event at Newcastle University in February; NanoMed 2006 in June; and the annual meeting of a European Newcastle-based biotechnology project in November where I was able to sit in on a work-package meeting and a coordinating plenary meeting. In 2007, I went to a European nanobiotechnology networking and idea-canvassing event in March, and to a European commercially orientated research networking event in June.

Most of these observations were in their style participatory, that is, I shared the perspective of other attendees with the intent of (1) learning how researchers communicate in these environments, (2) acquiring further information on NST, and (3) networking and recruit potential respondents (Burgess, 1984:81f). However, the design of these observations was not to collect 'raw' data directly entering my analysis, but to provide a coherent background for my case study. Initially, I had only a general notion about what to expect and what would be important outcomes of these observations (May, 2001:148). Thus, I had to constitute my own virtual background to my observations, which I mainly did through the literature review.

One of my observations was a project meeting. I had negotiated access to the event during an interview with a senior managerial scientist. I expected to experience examples of presentations on research progress and preliminary findings, and possibly crossdisciplinary discussions. During the meeting, crossdisciplinary issues emerged in the translation of research. Two work-packages in that project had to coordinate their research but difficulties had emerged in the translation between the researchers with different disciplinary backgrounds. The communication between the groups needed to be widened into interactive cooperation both at the meeting and afterwards to connect more closely their respective research tasks. This provided me with some ideas on interactive aspects of research practice, which later on I included in my interview aide mémoire.

At other events, such as NanoMed, the European nanobiotechnology network and the commercially orientated event, I observed communication of research, which at times turned into initialisation of collaboration. Also, representatives from social sciences or with commercial agendas were invited to give talks on the economic, ethical, legal or social aspects of research. Interestingly, scientists seemed to perceive the role of sociologists, ethicists and exponents with legal and commercial backgrounds mainly as advisers, either in regard to understanding and communicating with the general public, or in regard to taking their research further into marketable application.

*Preparing Interviews*

The choice of methods for my research was qualitative interviews. Despite, or even because of, having informed myself of SST, STS and NST in my literature review, I still needed to identify key aspects in scientists' perception of NST. At the same time, I had a range of significant themes to include in my interviews without limiting the outcome of the talks with respondents. Therefore, a semi-structured approach to interviewing seemed favourable. As Burgess notes, “the unstructured interview is rarely conducted in isolation [but often] draws on the knowledge that the researcher has of a social situation.” (1984:106). Because of my literature review, but also due to my experiences in several observations before I started the main interviewing process, I felt I had reasonable familiarity with the study of NST. Nevertheless, I intended my interviews to be purposive (along my themes derived from the literature review and my own interest in institutionalisation) whilst being open to allow exploration of respondents' perspectives, especially in regard to how scientists construct narratives of NST in connection to their research and research life (Mason, 2004:164). Therefore, I considered “interviews as conversations” (Burgess, 1984:101), open for tangents and foci on aspects important to the researcher, and to provide space for respondents to *narrate* their accounts: to establish connections and provide rationalisations (Mason, 2004:166).

However, my experiences with actual interviewing had so far been limited, my concern slightly amplified by having to conduct interviews in a language different to my native tongue. Therefore, out of methodological and practical considerations, I thought that a middle-of-the-road approach would be most appropriate in actually implementing my research: to prepare and conduct 'semi-standardised' (Fielding and Thomas, 2001:124) or 'semi-structured' (May, 2001:123f) interviews and rely on the help of what I have come to appreciate as the *aide mémoire* in asking questions, whilst being able to divert and probe.

I also decided on a semi-structured interview style to elicit researchers' perspectives in narrative form, but with certain questions relating to my themes and sub-themes to follow and to focus my interviews and analysis. This choice supported me in garnering understandings of NST, but also of science in general, and of social scientific and public agents in regard to science and NST from inside the sphere of research. In my interviews I looked for informing attitudes, perceptions, approaches, motivation and so forth, also in regard to processes of institutionalisation.

The interviewing process consisted of two phases: a preliminary phase of sensitising interviews with four senior members of a European network on nanobiotechnology, and twenty-one data interviews with researchers of all career stages at three universities in the North-East of England. My aim of twenty to twenty-five semi-structured data interviews was based on a local senior managerial scientist's estimate that approximately fifty physical scientists in Newcastle relate their work to NST. The number I aimed for seemed adequate both in regard to the estimated overall population and to the qualitative design of my fieldwork. In May 2007, I concluded the fieldwork phase.

The first, brief phase of interviewing involved travelling to different places in Western Europe in November and December 2006, and consisted of four meetings with senior social scientists and ethicists, with two of these having a scientific background. The rationale was to practise interviewing skills and gather supplementary information on issues of NST. The talks connected to debates around NST, and provided space to discuss perspectives in science practice. Both aspects contributed to the further development of my fieldwork.

The second, central phase of my fieldwork was the conduct of semi-structured interviews with scientists and engineers. A significant aspect in approaching and negotiating access to potential interview partners was to connect to their research directly. I did so by linking my overall research aim to their specific research interests, aiming to bring out what I considered to be the NST-link. Information regarding research interests were available on research profiles on the web pages of the three universities and their research institutes at which I conducted my interviews. These helped me to gain a preliminary understanding of researchers and their own presentation of their research. The narrative account of a respondent's view on NST starts there already, if subliminally, and influenced my decisions for enquiries. Simultaneously, this helped to explore scientists' understanding of NST.

Other 'recruiting' opportunities were 'nano'-events, or recommendations from colleagues. This proved particularly useful as I was interviewing elites. In most cases, however, the first contact with a potential respondent was via email. I contacted these in four email stages: in the beginning of November 2006, and then in each month of the first quarter of 2007, including single reminders.

*The Interview Aide Mémoire*

In preparation of my interviews, I developed an aide mémoire during spring and summer of 2006. The task started out as a very long list of potential questions, still more of an interview schedule than an actual impulse-giving and focus-providing aide mémoire. Eventually, I consolidated and divided interview questions into four main clusters: (1) on professional background, including job description, research interests, and disciplinary training; (2) on research experiences, including research connections to NST, and general aspects of research work such as staying informed in science and everyday tasks; (3) on experiences with collaboration in NST, covering aspects of organisation, communication and impacts of collaborative research; and (4) on future developments both in researchers' personal research lives and for NST as a field or discipline. Experience from the first six interviews in November 2006 and January/February 2007 led to a revision of my aide mémoire (see *Appendices*). I consolidated my aide mémoire to questions around disciplinary background; NST connectivity; and NST collaboration. Respondents' reflections on these diverse but interconnected questions constructed coherent narratives on their perspectives and experiences with NST (Andrews *et al*, 2004:113).

*Conducting Interviews*

In most cases, interviews were booked well in advance and took place either in researchers' offices or in a general recreational area within the academic context, such as the common or coffee room. The first data interview, with a postgraduate researcher, took place in the Sociology department owing to the request to meet up after work. There, I had more or less control over environmental influences regarding noise levels and potential interruptions. Generally, however, these were issues that sometimes interfered quite considerably with the interview process (cf. Roulston *et al*, 2003:648ff).

In most cases, the interview procedure was constituted as follows: introduction and brief summary of my research; address of ethical issues such as informed consent and confidentiality; the interview process; a brief general talk concluding the meeting. I distributed a participant information sheet for further references, and asked participants to read and sign the consent form (both forms see *Appendices*). All of my interviews, bar one, were recorded, and none of my respondents requested a transcript. However, one or two of my interviewees expressed interest in reading a study report as they were interested in the matter of collaboration in NST and science in general.

In the first round of interviews, I often felt uncomfortable, having to get used to the process of interviewing both in English and talking with scientists about aspects of their research life they might not have considered in the ways I asked them to before. Whereas in my native tongue I have no difficulties bridging moments of awkwardness, rephrasing my questions or reacting quickly with probing or change of style, I had to get accommodated to these techniques in English. My interviewing techniques improved once I had conducted six or seven interviews, when I became aware of how my questions might be received. Accordingly, I revised my aide mémoire. As I was relying on the social model of research, and also on sociological concepts in the phrasing of my questions (identity, collaboration, disciplinarity, institutionalisation), translational problems occurred. These emerged when trying to explore researchers' understandings and experiences narrated in scientific terms and informed by scientific understandings. Therefore, in later interviews I consulted only a small list of questions collected in my revised aide mémoire. Pursuing the intended conversational method proved to render interview experience more fluent and interesting. Not in all situations did this work as well as in others, as sometimes researchers were less forthcoming in engaging with enquiries, or were concerned with the phrasing of their answers.

Reflecting on my research experiences, I contend that interviewing academic scientists can be understood as interviewing elites. Although the issue of relational power is not at the heart of my study (cf. Aberbach and Rockman, 2002), the position of participants and the resulting analysis suggest this to be the case. Kezar (2003) describes and suggests different principles of elite interviews, which relate to my study. I suggest that the focus on (1) scientists' specific experiences and *tacit knowledge* in relationships (*collaboration*) with others; (2) their subjective *reflections*; and (3) the aim of my study to explore and identify impacts and changes regarding the *situation* of scientists relate to Kezar's discussion and connect to traditional understandings of elite interviews. Although Kezar focuses on the conduct of interviews, I believe that her proposal implies foci and aims similar to mine.

Interesting for a reflection on my interview experiences with academics as elites is that power issues emerged between a small number of interviewees and me as the interviewer. Power can be derived from (1) the position the respondents hold, for example as managerial scientists or academic supervisor; (2) from academic authority (merit and seniority); (3) but it can also be claimed via experiences in day-to-day interaction, as in the case of clinical scientists and their experiences with patients. At the same time, the power potential can be far more fluent and shifting in an interview (Smith, 2006:644f), for example between feeling challenged, and challenging. In the section on *Ethical Issues* I provide an example of trust in research interviews.

In two cases, senior researchers, incidentally both clinical scientists, showed mild disregard for social research on scientists' perception of NST and research collaboration as examples of the relation between science and social science. This could be due to feelings of challenge to their positions as scientists or medical and clinical researchers, fields that are perceived as socially benign. It is, however, more likely that this disregard relates to differing understandings of the role of social science, with scientists often perceiving social science as science's 'hand-maiden', as a service-provider and interpreter between science and society. I remarked on these perceptions in my reflections on observations at NST-events. A very small number of senior managerial scientist also regarded some of my questions as unintelligible or irrelevant, particularly when a commitment to a definite answer was required (cf. Aberbach and Rockman, 2002:674). At the same time, some of my respondents found my study and the questions asked topical, or often, were simply indifferent to the study itself. Researchers were usually happy to talk about their work, even though sometimes an initial threshold of suspicion had to be overcome.

Most interviews were about an hour long, with some taking only thirty to forty minutes due to respondents' late arrival and subsequent appointments, or because of disruptions. A small number of interviews took about ninety minutes, with one or two close to two hours. The most comfortable and productive timing was of just under an hour, and taking place in the early mid-afternoon as respondents would be able to focus on my questions often without feeling pressurised by subsequent commitments, or simply by regarding the interview as a break from work. Several of my respondents I had met previously at networking events, so we were able to slowly ease into the interview as well as keep it conversational. Also, these previous meetings helped to provide the interview with examples of collaboration or research as we were able to relate to these.

Overall, the interviewing experience was complex. Interviews provided rich data and allowed for my analysis to be comprehensive. However, preparations were profound and time-consuming, amplified by the status of many of my respondents as senior or managerial scientists and their awareness of the strongly felt differences of science and social science as well as levels of seniority.

## 7 Ethical Issues

As with any information gathered in research, then analysed, interpreted and disseminated, there are ethical issues to be addressed to render said research ethically sound. This soundness is mainly expressed in ensuring that respondents and participants' dignity and safety are not jeopardised, and that the researcher is also safe (Bulmer, 2001:51f).

The most apparent ethical issue regards the approach of potential research respondents or participants, and the role that the social scientist takes on or accepts. In my fieldwork, I attended several NST events, most of these large networking events. The issue here was that I had interests of both a participant and an observer, by aiming to learn about NST research and NST as a field, to observe scientists' collaboration and networking, and to raise my awareness of potential respondents with possible subsequent recruitment. Thus, the interpretation of my role here lies in (1) the understanding of what constitutes research (cf. Burgess, 1984:200) when my aims were manifold, and (2) that one of my aims – the one as observer and not as participant – was not to take notes of individuals' opinions but to gather an overall feeling of issues of science communication and collaboration at idea-canvassing and networking events.

*Informed Consent*

In all cases, the lead organisers of the events were aware of my position as a social scientist as I included this information in my registration. I also talked to two organisers before attending 'their' events. When asked about my research background by other participants during all events, I openly discussed my aims and rationale for being there. Therefore, to some researchers at those events my role as participant observer was 'open', to others it was 'closed' (cf. Burgess, 1984:199). However, the nature of my observations was not covert. All networking events took place in the public domain, allowing researchers from all backgrounds to attend and take notes.

Of a more sensitive nature was attending an annual meeting of a research project to which I was invited by the organiser. I sat in at two meetings, a focused work-package meeting, and the plenary meeting of all project members. The participants of the small research meeting were aware of my position as an outsider and researcher before any discussion commenced, and were aware of me recording their exchanges. Retrospectively, I decided not to use the recording but to rely on general impressions from the discussion in the meeting. During the plenary meeting, I also confined myself to gather a general impression of communications. Therefore, informed consent was not required considering the supplementary nature of these observations for my analysis, and that no harm could in any way come to the attending scientists and the event organisers (cf. Bulmer, 2001:49; Burgess, 1984:200f).

In the interviewing process, *garnering* consent was, at least in its conduct, straightforward. I explained my research and the procedure of the interview in the first contact (email); in telephone follow-up when requested; and before I started the interview. At least twice in this process I had pointed out how I would deal with the recording and safe-guarding of interview data. I also made my respondents aware that they could opt out of the interview at any time and refuse the recording of the interview. I then asked them to read and sign the consent form.

*Confidentiality, Anonymity and Non-Identifiability*

The issue of informed consent regards in particular confidentiality of data and respondents, and ensuring the anonymity and non-identifiability of my research respondents because of the small community of scientists in this case study. Respecting the confidentiality of my respondents by not discussing their views in relation to their person, and thus trying to render data as anonymous as possible, spanned the whole of publications, presentations, but also interviews with potential colleagues of the interviewee, and discussion with my colleagues. As mentioned above, the main issues of this case study was that of a relatively small and tight research community in the North-East, especially at Newcastle University. I believe that in these circumstances it is rather difficult to make sure that absolute anonymity is warranted in the analysis of researchers' views and the use of interview excerpts in form of quotations. That might have been one of the reasons of why a small number of very senior scientists and heads of institutes ignored or refused requests for interviews. Also, some senior managerial researchers voiced their concern that the recordings would be secure – which I assured them of – and that their comments be treated confidentially, especially in regard to their views and potential ramification these might have on their position and organisations.

However, there are a number of ways, which I as the researcher have taken to control these issues of confidentiality, anonymity and non-identifiability. Some regard the safe storage of records and transcripts, and the sensitive management of data from interviews. Already in the transcribing process of the interviews, in a small number of verbatim and then predominantly partial transcriptions, I omitted directly identifiable information such as persons' names, full-name institutional affiliations, and I avoided to specify research projects, especially ongoing ones. I have assigned each respondent and their transcript a running number, for example 'Researcher14' or 'Researcher25', numbers that correspond to the sequence of interviews arranged, but include interview numbers not conducted or not included in the analysis. In the analysis chapters, these are the denominations for quotations of individual researchers. In cases of quotations allowing direct identifiability, especially in combination with previous or following quotations, I have changed the numbering style to an additional level of anonymisation using consecutive letters, for example 'Anonymised Researcher A'. All subsequent, thus additionally anonymised, quotations of the same researcher bear the same letter (A, B, C and so forth)

Sometimes, researchers asked me not to disclose certain information, which I then omitted from the analysis. Others would, after our talks, find that the content did not warrant any specific disclosure agreements. One researcher preferred not to be recorded at all, and I have not quoted from this interview in my analysis. A further way to ensure non-identifiability, that lies in my control, is not to discuss the potential identities of my respondents.

During my interview data collection, I realised that there are difficult political issues within the North-East of England in regard to institutionalisations of NST and funding matters for nanotechnological research. This might have presented a hurdle for some scientists to participate. At the same time, this produced an additional ethical issue of whether to include discussion of this in my quotations of scientists, or in my thesis at all. I decided against the former, but have made references to these institutional political issue in my analysis without elaborating on it. I argue that, especially for a case study, this local and regional issue can simply not be ignored as long as it relates to my research aims and questions, that is to the nature of NST, its understanding and its practice in the North-East (cf. Silverman, 2006:327). Some of the researchers I interviewed asked me not to discuss their views on this matter, and I have not done so to preserve and honour the trust of my respondents, both in regard to protecting and respecting them. One or two respondents asked me to confirm with them any quotations used in future publications.

In regard to trust there was another aspect that I had to consider in my fieldwork. Sometimes, it appeared as if researchers felt they were being monitored or audited, owing to the nature of my questions about research collaboration and research tasks, for example how they kept up-to-date for their respective research projects and research areas/fields. I affirmed that my study was not intended to be an evaluative device. Before I started my fieldwork, I would not have expected scientists to be partially defensive about their research practice when asked by me.

A work-related ethical issue was that respondents were spending some of their research or recreational time with me, whereas I was not able to compensate them in any other manner but by showing interest in their work and their opinions, and by making the whole interview experience as positive as possible.

*Data Management*

Having completed my study, I deleted any files containing respondents' names or relating interview codes to respondents' names. However, I have kept and intend to keep the (encrypted) digital data records from my interviews, as well as the (coded and anonymised) transcripts, for a further twelve months. Transcripts are in the majority select transcripts. I plan to publish my findings from this research over the course of the following year, which will benefit from continued access to the raw data for final correlations. After these twelve months, I will erase data files and transcripts, thus concluding the analysis of this case study.

## 8 The Fieldwork Data Analysis

Early on in my research, whilst conducting a literature review, I came across Latour and Woolgar's “Laboratory Life” (1986) and Ludwig Fleck's study on the production of science facts and communities from 1935 (in the edition of 1980), which influenced me to focus on scientists as key informants, and on the nature of collaboration as basis for understanding an emerging field. I sought to expand the line of social research of science into the social sphere of science conduct where research takes place and scientific knowledge is produced. Latour and Woolgar's idea of *order* in the research process (1986:244ff) and Fleck's thoughts on the scientific *cognitive collective* (1980:146ff) provided the impetus for me to expand my analysis towards exploring the structure and practice of NST.

Also informing the thrust of my analysis were studies on 'biotechnology' and its sub-areas as a new and emergent field of science and technology (for example Hedgecoe, 2003; Kivinen and Varelius, 2003; O'Malley *et al*, 2007), which, it can be argued, provides many parallels to NST. These studies prompted a number of ideas in my analysis of NST. Therefore, my analysis has begun with the review of debates around science; of science practice in an emergent field similar to NST; and of the field of NST itself. My analysis is embedded in the interpretative research approach I have taken, in the choice of research aims and foci, its themes and the methodology.

*Links between NST and Biotechnology*

Kivinen and Varelius call the field of biotechnology a 'superscience' (2003:141) because it brings together expertise from diverse established disciplines from biology over physics to engineering. This reminds of descriptions of NST as basic and encompassing technoscience. I consider the disciplinary nature of NST extensively in my analysis, exploring the role that disciplinary backgrounds and disciplinary expertise play in the conduct of nanoscale research. Numerous sub-entities make up biotechnology, such as genomics and pharmacogenomics, synthetic biology and systems biology. This diversity seems comparable to NST's research areas of nanomagnetism, nanomedicine, nanobiotechnology, nanofabrication, nanofluidics and so forth. The difference here, of course, is that the former group is divided into areas of increasing systemic approaches, whereas the latter is mainly based on scale and the specific characteristics and properties of matter at that scale. However, both fields are embedded within the greater context of the 'real world', that is technologically they need to be, and rhetorically they are, deliberately connected to the macro-world and its applications by scientists, but also to societal interests that go beyond scientific or technological considerations. In fact, both fields have a distinct commercial element to them. Kivinen and Varelius refer to the 'Silicon Valley Rhetoric' (2003:144) to describe the hype and promissory nature of biotechnology, strongly endorsed in the 'triple helix' of industry, government and university with commercial and macro-economic aims (*ibid*:146ff). As I showed in the previous chapter, NST as a social field is immersed with commercial references and implications, and this immersion impacts on the boundary work of scientists, but also on their research interests and their motivation for collaborations as I contend in chapters 4 and 5.

The promissory and visionary nature of NST, which features strongly in the social debate around the field, provided the grounds for many questions and considerations in my analysis, and it is reflected in all of my analysis chapters in one way or another. For example, visions embedded in labels such as NST, or pharmacogenomics as in Hedgecoe's study (2003) of this research area, matter because they have 'rhetorical strength' (*ibid*:516), even if my respondents strongly distinguish between 'real' science and visions or promises. Their boundary work is reflected in definitions of what nanotechnology is about. It also reflects on individual disciplinary backgrounds, and thus in research identity (cf. *ibid*:515f). Setting out from another example – biotechnology – and the reflection of its social context, which is linked to NST scientifically and socially through the areas of nanobiotechnology and nanomedicine, has given some leads for the analysis of my data.

*Connecting Findings*

My literature review, and experiences and findings from the first round of interviewing in the beginning of 2007 helped me (1) to revise my aide mémoire, thus leaving more leeway for my interview partners to respond and explore questions, and (2) to start familiarising and reflecting on my data. In developing an applied understanding of the two themes of collaboration and research identity in NST, I was able to probe further in later interviews.

Organising the data, I started out transcribing four interviews verbatim. However, owing to the theoretical approach and strong research themes of my study, as well as establishing familiarity with the interview contents – overall I listened to each in full for three times – I changed to a more pin-pointed transcribing process of selecting key passages. The three themes, disciplinarity, collaboration and identity, connected well with the main threads of respondents' considerations, for example (1) disciplinarity with research training and specialisation; (2) collaboration with communication and motivation; (3) identity with research interests and projects, among others. Also, the interconnectivity between themes and between main threads became apparent, respondents' 'narrative strategy' (cf. Chase, 2005:663) emerged and could be followed. This pin-pointed approach has been made easier by producing a summary for each interview, helping to evaluate the significance of passages while keeping a summary record of all interview contents.

Choosing key passages from my interviews eased the burden on my time budget considerably. I interviewed scientists who had come to work in the North-East from all over the UK and abroad, and I found myself listening to significant parts of interviews repeatedly due to various dialects and individual speech patterns. Other factors were differing acoustic situations in interview environments, and unfamiliarity with specific terms and phrases. I correlated words and phrases, as I understood them, with information on the internet, trying to open up the to me codified constructions of meaning. In inference to the context of these words and phrases I was able to establish understandings in most cases, which proved to be significant as brief phrases often summarised the respective respondent's view on a particular aspect, or they provided additional understanding. Often, I did not ask for their meaning during interviews as I did not want to interrupt the flow of the narrative, or because I focused on other aspects of this narrative during the interview.

Other speech idiosyncrasies featured as well. To make passages more easily readable and focus on main aspects in my analysis, but also to avoid portraying very distinct speech patterns, I avoided transcribing repetitions and non-verbal stalling elements. As my study does not rely on communication analysis this choice seems particularly legitimate.

During the various stages of analysis I tested and trial-formulated ideas in presentations to colleagues both within and outside the Sociology department at Newcastle University. In that way I was able to improve conducting practical and theoretical aspects of my analysis parallel to each other, organising ideas and connecting these to the theoretical framework. This influenced my research trajectory by slightly changing my research outlook, which started out with a focus on exploring the collaborative nature of NST. The main aim of my study has incrementally changed to exploring and providing means to understand disciplinary structure and research practice of NST. This has been influenced by my data and the subsequent analysis, of course, and by my increasing awareness of STS and NST as research fields.

*Analysis Structure*

In my analysis chapters I developed an approach to explaining how NST is constructed in identity negotiation (chapter 4), collaboration (chapter 5) and in the distinction between academic and non-academic, and scientific and non-scientific aspects in NST research (chapter 6).

For chapter 4, I began my analysis by exploring the socio-technological world of scientists. I identify three dimensions of scientists' identity negotiation in contemporary academic science as reflected in the accounts of my respondents. These dimensions constitute the foundation for my subsequent analysis of how NST features in scientists' accounts of research identity and collaboration. The development of my analysis here is influenced by an understanding of contemporary academic science as increasingly crossdisciplinary and cross-boundary, which are defining elements of 'Mode 2' knowledge production (Jacob, 2001; Nowotny *et al*, 2001).

In chapter 5, I take my considerations of NST in the socio-technological worlds of scientists further by exploring the element of collaboration. I scrutinise how and why collaboration emerges in science, and what the defining aspects are. This connects to the role of disciplinarity and epistemology in NST research collaboration, and thus incorporates elements of identity negotiation.

In chapter 6, the elements of identity and collaboration feature in the boundary work of academic scientists towards non-academic and non-scientific elements. This chapter provides an outlook of how demarcation takes place in academic science. I use examples for my analysis here – collaboration with industry and funding strategies – which are integral to contemporary science practice and feature heavily in my respondents' accounts.

## 9 Summary

In this chapter I provided a brief historical account of my approach to fieldwork and analysis by (1) considering the methodological background of my study, (2) elaborating on the choice of methods, and (3) discussing issues of practical and of ethical nature that emerged during the research.

For my research, I have chosen the methodology of a case study to gain insights into how scientists view and experience their ever-day research life and what impacts this might have on contemporary research practice in academia. Taking this 'snap-shot' has allowed me to identify and examine aspects vital to the understanding of NST and other emergent research fields by focusing on an example that is nevertheless connected to the wider context through many strands. The combination of analysis input from semi-structured data interviews and informing participant-observations has provided me with rich data of perceptions and their 'lived' background at events, meetings and conferences. The focus on three main themes has helped to contextualise as well as reconstruct the case study findings. I have rigorously followed up on decisions from my analysis (influenced by the literature review and analysis, and early interview data and observations) in the stages of my study to render it coherent and provide a narrative that makes aware of idiosyncrasies of NST in general and in the North-East of England, whilst simultaneously embedding this study of NST into the wider debates around contemporary academic science. The main analytical findings show that the aspects of my research themes are interconnected and relate to the overall accounts given by respondents, tying in the case of the North-East into a larger structural context (cf. Mason, 2004:177).

My study focuses on the mainly laboratory/office-based every-day scientists as key actors in the production of knowledge in NST. So far, the voices of scientists most often heard in the debates around science and NST are those who represent political agendas connecting science and society, and therefore need to polarise to present alternatives in the tension field of political negotiation. The analysis of my research embeds research practice of NST in the debates on NST and academic science structure and practice. The following analysis chapters flesh out these thoughts.

# Chapter 4: Socio-Technological Worlds in NST

## Disciplinarity in Research Identity

Chapter 4: Socio-Technological Worlds in NST

## 1 Introduction

In this chapter I explore how researchers construct their *research identity* in reference to their everyday research work, to their research interests, and in regard to Nanoscale Science and Technology (NST). My focus lies on identity aspects of disciplinarity and thus connects to the issues of disciplinarity and to boundary work in the debates around NST.

I also consider some of the rationales and motivations of researchers (funding, technological advance, requirements etc.) referred to in the construction of identity. Thus, the first part of the chapter looks at general notions in science practice of (section 2) disciplinary background or affiliation; (section 3) research interests and motivations; (section 4) aspects of disciplinarity in the choice of information for research, such as journals, conferences and peer advice; and (section 5) the division of labour in research as an indicator of the different types of researchers, and the possible implications of research experience and research tasks on researchers' disciplinary identities.

In the second half of the chapter I enquire further into the social construction of identity in NST. Examining researchers' understandings of this emerging field provides a basis for analysing their positioning towards NST. This connection features in the extent of utility or institutionalisation they grant NST as a field. I follow up on this by looking at disciplinary boundary work, or attempts at framing NST, in reference to existing notions of disciplinarity and paradigmatic scaffolding.

I rely on three concepts in my analysis: 'discipline', 'field' and 'area', each with an increasing requirement for specialisation of knowledge and skills. For my study, I define the three concepts as follows: a *discipline* is an institutionalised framework with a specific approach to the world, and with a generic set of knowledge, skills, methods and tools that constitute disciplinary expertise. The *field* is constituted by focused scientific enquiry along a defining element such as scale or application, often transgressing disciplinary boundaries, thus drawing on different specific aspects of disciplinary expertises. An *area* is a specific part of that field. For the field NST, which focuses on research at the nanoscale, disciplines are physics, chemistry and so forth with their specific expertises for approaching the nanoscale, and the area within that are 'nanofluidics' or 'nanomagnetism', among others. Nanomedicine, for example, seems to be a special case with its very wide medical applications. However, my distinction between field and area is intended to clarify the specialisation requirements between NST and its areas, and possibly sub-fields.

## 2 Construction of a Disciplinary Background

On researchers' awareness of their own disciplinarity and its negotiation

In New and Emergent Science and Technology (NEST), research expertise appears generally to transgress disciplinary boundaries as the fields of enquiry both in basic and applied research become increasingly complex and problem-orientated (cf. Nowotny *et al*, 2001). This is especially visible in the case of technology production where research from across many sciences is brought together toward specific applications. The branding of technology fields, such as biotechnology, micro- or nanotechnology, is an indicator of this development. The scopes of the field are broadening, and only the lowest common denominator, or most novel aspect, of the technology field is used as a label. For a researcher to be able to contribute meaningfully to one or more of these fields, specialisations and specific skills become increasingly task- or area-focussed. Thus, researchers' expertise cannot be broadly discipline-orientated in their practice. Rather, they need to focus on certain techniques, models, systems and so forth. This implies that the construction of a disciplinary-based research identity in specialised fields and areas is complex, particularly when these fields and areas are of a crossdisciplinary nature.

*A Trinity of Research Identity*

Researchers often tend to make a distinction between their disciplinary background dictated by their training and research interests, and their current disciplinary framework, often described as an area or field of particular interest, dictated by personal interests and external influences that encourage specialisation. The distinction is bridged by personal interests, compatible through the increased specialisation of expertise and gaining of new knowledge and skills built upon existing training. Scientists' interest fields can be quite broad with a focussed specialisation, which is narrated as connected to what has been done in research before.

**Researcher12:** "[It]'s chemistry background with biochemistry and clinical exposure, and then development of technologies to meet those demands."
**MW:** "[W]ould you place yourself within a discipline?"
**R12:** "No, not a single discipline."
**MW:** "Maybe a specialisation?"
**R12:** "I suppose, I mean, [pause] on a kind of talk-level thing, it would have to be Biochemistry. But it's always qualified [...]."

The perceived or intended disciplinary affiliation does not cover the whole range of activities the researcher engages in. Indeed, such a disciplinary fixation would be mostly meaningless in everyday research. Instead, I argue that research identity is constituted by three dimensions of identification reflected in the accounts of my respondents: (1) the *belonging* or *structural* dimension, which is directly referred to and can be interpreted as attempts to position oneself on the disciplinary map of science, and thus in existing regimes of research reasoning, funding, publishing, peer review and institutional affiliations; (2) the *practice* dimension, which describes the actual expertise of the researcher, the specialisation within the complex grid of disciplines, interests and specific skills and competencies, which *distinguish* this researcher from others and enables him or her to contribute to research projects; and (3) the *strategy* dimension, which is mostly implied and presents *potential* research and emerging interests, and points of further specialisation.

**Anonymised Researcher A**: "So, Physical Chemistry is the broad area, and what I do within that is optical spectroscopy, mostly. [...] So that's the main area. And the topics that I usually investigate are around DNA. So, nearly everything I study involves DNA in some way."

Following my proposal of three dimensions, constructing an identity as a researcher then consists of the attempt to be as precise as possible in the definition of one's own expertise, and the openness of the research interests or research fields that one can explore. The disciplinary identity, it appears, takes on the shape of a 'conflict'. This is a conflict for acceptance in the 'state' of science. It is conducted by strategically or even reflexively affiliating with, or referring to, the 'canonised' sciences such as physics, chemistry and biology. Established mega-fields of research application such as material science, engineering and medicine, also provide reference points.

*Consumption and Identity*

However, simultaneously, specific expertise has to be brought to the fore, which distinguishes researchers and their research from peers. This mechanism has been observed and described outside of science as a constant negotiation of identity through consumption (see for example Garot and Katz's research into gang-related dress codes (2003); Redden's study on New Age consumerism (2002); or Warde and Bennett on consumption among elites: (2008)). In the case of knowledge production this could be seen as consumption of organisational and educational references, existing or emerging areas or fields that correspond most closely to one's own research interests, and access to funding streams and equipment.

> **MW:** "How would you characterise the area, or the discipline that you're working [in]. You mentioned materials engineering before. Is this the way how you would characterise it?"
> **Researcher15:** "It's changed over the years. Probably about ten years ago it was sufficient to talk in terms of materials engineering, materials science. And then, sort of as speciality of that, that time was corrosion management and surface engineering. Now, because of different funding streams and [the] different direction that the Institute's gone – we've changed direction somewhat – so, one of the emergent issues is nanotechnology. That's reflected in funding streams at the national level and the regional level, and [we] took advantage of those. And we [...] recast what we thought the Institute was about, so we've called some areas off of research and we've gone into other areas."

This consumption, I contend, influences the negotiation of identity in a number of ways. It impacts on decisions regarding (1) the research area to pursue, or along which (sub-)disciplinary lines to locate one's research; (2) where to apply for funding or institutional affiliation (for example employment, project partners or further education/training); (3) where and how to publish and thus subject one's research presentation to a certain regime of referees and peer reviewers, either discipline-open and focused on a research field or quite closed and discipline-oriented; and (4) what sources are adequate for personal research (journals, conferences, collaborative projects).

When enquiring into where researchers would locate their research, the responses can also include references to required expertise that is not their own. This is mostly done in the context of research into technological applications, but does also extend into basic research.

> **Anonymised Researcher B**: "That's tricky. It's a big grey area between an awful lot of... almost like a grey area between a lot of schools. I have a physics background, I work in, you know, the electronics, electrical engineering, there's obviously some material science in what I do, (some aspects) in nanotechnology what I do. And then there is the application. So, we got space-based, volcanic, so we're doing geo-physics, chemistry. There's so much chemistry in this that I have to keep going asking chemists what various things mean. So, I'd say I *live* in a grey area that's between lots of, sort of traditional academic backgrounds, I think. That's probably the best description I can come up with." (emphasis added)

This reference provides the setting for personal expertise as part of the *practice* dimension of research identity. In this quotation, there is a strong distinction between the training background and the area the researcher works, or even 'lives', in now. The personal expertise is defined by which other expertise it can complement. Interestingly, 'foreign' expertise is hardly ever clearly distinguished. It mostly hovers at the threshold of (sub-)disciplinary accreditation with possibly a focus on research techniques and skills that are contributed by project partners or research informants.

In summary, I argue that researchers claim their disciplinary identity by negotiating the dimensions of belonging, practice (implying capability) and strategy. They do so by making choices comparable to consumer choices in the development of their research specialisations connected to existing structures in science. This enables them to distinguish themselves for research contribution whilst belonging to structures of institutionalised science that allow for funding, recognition and participation.

I focus on disciplinary identity construction in collaboration in the following chapter and shall further elaborate my interpretation there. On the following pages, I explore drivers influencing the negotiation of research identity, thus taking a closer look at the above mentioned interests and motivations and their setting within science regimes.

## 3 Research Interest and Motivation

Context and drivers for research and identity

As indicated by my consideration of the role of consumption above, research identities seem to be negotiated in relation to available points of reference instead of creating or relating to entirely new ones. The social structure of science, of which researchers are a part and constantly negotiates their place in, connects to research identity through choices and preferred means of identification that are influenced by structural requirements. Researchers seem to rationalise their choices and identification along a number of such markers. These are made up of a complex array of (1) personal interests and expertise, (2) external requirements, strategies and scripts, and (3) the availability of and access to external sources such as funding, equipment and expertise of others, which are provided on grounds that influence the ways researchers construct their identities.

*Research Interests – Research Limits*

The impact and satisfaction of personal interests will provide a researcher with the grounds to commit to a certain field or area of research over an extended period of time (that is for longer than a project's duration) while still being able to correspond to scripts that the regime of science expects the researcher to subject himself to. These scripts consist of building up a specialisation of expertise, and a track record of research experience and publications that merit the access to funding, institutions and project partners, thus provide for the livelihood of a researcher by entering and proliferating the “cycle of credibility” (Packer and Webster, 1996:428). Interest in specific processes or systems, but also specific approaches to research, provide guidance into which area or field of enquiry a researcher will go, which disciplinary input to refer to.

> **Researcher14**: “I am not particularly interested in the bio-side, I have to say. I'm interested in the mechanics of the bio-side. So, if somebody starts pushing and poking, pulling cells and twisting them and doing things like that, that's quite interesting to me. But I'm not interested in biochemical pathways and modifications, and... I don't, I mean, have background really in approaching chemistry and things to deal with any of that. So, I would tend to deal with what's more the physics end of things, solids.”

In the course of negotiating identity, previous interests and acquired knowledge and skills contribute to the specialisation that will constitute the expertise a researcher can identify with and then proceed to establish further.

> **Researcher20**: "So, when you look at a system, you'll think of it from the viewpoint of, I guess, what you've studied before, what you know before, and hence what you think you can look at in the future. I don't think you can go with a completely blank mind, you're always conditioned by your previous experience and previous knowledge."

Therefore, research interests and training seem to be mutually influential on that intended path of increasing research merit and seniority. Both are measured along certain criteria, such as the track record, which in turn can be constructed from references to citation indices; institutional affiliations such as fellowships or chairs; and activities within the community of peers such as refereeing or teaching, among others. Thus, personal interests and expertise are situated in or contextualised by structural requirements (criteria). These requirements encompass the drive to conduct basic research or develop applications that are perceived as viable for other fields inside or outside of research; comply with science policy strategies, including funding streams and institutional orientation; and conform to general scripts of scientific conduct such as building up the aforementioned track record or submitting to peer review.

> **Anonymised Researcher C**: "Mainly because my funding has come from cancer research charities. So, I suppose that has given me a profile as a cancer researcher, although my interests are much wider than that."

> **Researcher12**: "We are driven by what the clinicians require, what they desire, what they think that they need to have. So, if they say they need to, be very good if they could measure a particular species, then we develop a technology to allow them to do that."

> **Researcher18**: "The point is to publish papers, to do some new discoveries. So, you have some idea and try to do experiments, and if it works you analyse data and publish [a] paper."

It seems likely that it can be rather difficult for scientists to leave an area or field of expertise and build an entirely new set of skills and specialisations with the same success. This sounds especially convincing when considering researchers' relation with the structure of which they have become a part of. Gradually, the process of learning will enable a researcher to enquire into further aspects of a specialisation or push its boundaries. At the same time, external factors can prohibit the pursuit of research into quite different perspectives of gained research merits, or even other areas. Unless applied definitions of the 'extended' research interests, for instance in open calls for funding or scoping calls to explore a new field of research, allow for these to be included.

> **MW:** "Will you go on from there, will you enquire further?"
> **Researcher25:** "I wanted to, we haven't got any grants now, so it's kind of stopped. It's very difficult to get a grant funding for this project. [...] I know they wouldn't fund it because they said I haven't got a track record in the area, which I didn't, so I didn't have any publications in that area."

On the other hand, internal and external drivers can create synergies in that external requirements or scripts – such as following funding streams or accumulating extra expertise to take on a more administrative or managerial routine – influence how interests are developed or even formulated.

*Science Citizenry*

In a science that is accountable to policy dedicated to secure funding and support for the conduct of research (cf. Jacob, 2001; Rip, 2005), research acquires strong political and economic dimensions. These are acted out in navigating within the scripts of science and producing results or applications that can be traded within a market-like arena. Using classic categories from political philosophy describing the elements of citizenship, scientists are both *bourgeois*, economic citizen, and *citoyen*, political citizen.

Researchers' lives clearly have an economic aspect. Acquiring funding in order to provide materials, infrastructure and eventually conduct research is one of the most prominent considerations of scientists. In fact, funding has been a reason for a number of researchers to relabel their research for grant applications.

> **Researcher11:** "I think you have to ask yourself the following: what drives research today? And what drives research today is basically getting grants. And getting grants will depend on what the latest fashion is [...]."

The political dimension of contemporary research is its governance aspect, both within the sphere of research and between the spheres of governance and research. Funding allocation obviously plays a significant role in this. It is either directed through science policies, a case in point being to make funding available for politically opportune technology research, or through the self-referential refereeing process. Regulation, as a second aspect, is quite closely connected to funding processes through legitimation and accountability as well as institutionalisation and hierarchies. It encompasses regulation on how research is done (practices, methodologies), who can be involved, and which reasoning will be followed; all in the context of science as a social structure. Simultaneously, it also concerns regulation in regard to the real world, for instance 'health and safety' laws for the workforce or for the application of technologies and products, and normative considerations of legislative, ethics and theology. I further elaborate on these aspects in chapter 5.

*Research Interests and Funding*

In my interviews, scientists have pointed out that research funding increasingly requires the cooperation of academia and industry, but also that researchers need to adapt their outlook and expertise in various ways. Retrospectively, those decisions can be made to look intentional by their proponents, but the general scripting of scientific research is a force that researchers could not resist in most cases anyway.

> **Researcher14:** "But [it] would be noted that I tend to work on the very thin coatings, which is quite unusual for the general area. And that's the niche [...] to be in [...] which is not mainstream [...]. So there is a nice crossover between [the] traditional electrical engineering view [...] and the surface engineering view that I would have taken from my previous background."

> **Researcher15**: "Probably in the last ten years, I've deliberately tried to arrange my outlooks so that I can think in terms of an engineer or a scientists or a manager. If people are very specialised, they can at least try to step out of [their] speciality and look at it

> from different ways."

Whereas Researcher14 refers to a 'niche' when contemplating his research, something that has evolved from the area he is working in and his previous background, Researcher15 speaks of enlarging his view to be able to take on different perspectives. These two quotations might seem contradictory at first sight, but both express the necessity to adapt to the science context and represent different strategies to do so.

Funding as a factor also features in the third category of markers that I list. It is part of an intersection of access to and management of economic, cultural and social capital. These encompass grants and equipment; access and adaptability to collaboration with researchers of different expertise; and social skills for networking, the setting up and the running of collaboration.

> **Researcher19**: "It's just networking, really. And sort of word-of-mouth mainly. You can go to conferences and that, and you might have one, you might see one or two sort of good ideas of areas to explore. But it's pretty much only when you are doing work in that field that you actually get to know it properly. It usually involves a project or working with somebody [who] is bringing in that new field."

My data indicates that the elements of research interest and motivations examined in this section are grounded in bringing to bear *practice* and *strategy (potential)* of identity by negotiating and 'selling' one's own expertise. These dimensions are very much part of the day-to-day activities of research and thus far more fluid in their evaluation than the dimension of belonging. Generally, the negotiation of interests and expertise, requirements and scripts, and funding and equipment seems to require a constant re-evaluation of all three dimensions of the disciplinary identity. These are influenced by internal factors such as interest and learning, and external factors that are provided by the social structure of science. An interesting exception could be the holding-on to more traditional disciplinary affiliation that can be traced in senior researchers' construction of their self. This can speak of a stronger *belonging* dimension of identity. This first aspect of identity seems to take on a stabilising and system-adaptive function that is rather remote from every-day research life.

# 4 Disciplinarity in Sources of Research-Information
Every-day sources of disciplinary research identity

In my interviews, a number of informing sources have been brought up by my respondents. I categorise these sources as *codified* as they are addressing specific audiences; are using expert or technical language; and are covering certain areas or fields of research. These sources seem central to informing scientists' research and to the perpetuation of social and institutional structures of science in practice. I divide these sources into two main categories, conceptualising them according to the degree of structure: (1) *platforms of closed exchange*, including journals, text books, project reports; generally literature providing context for specific research, and (2) *platforms of open exchange*, such as conferences, fora, discussion groups, project meetings, initiatives and other membership organisations. Closed exchange takes place within a very structured space both of style and time, focusing on the presentation of (successful) research, or providing interpretations of various kinds. Open exchange is less formal and more practise-oriented, with a focus on problem-solving and emerging issues.

*Belonging and Practice Dimensions in Research Sources*

Researchers contribute to, draw and rely on these sources by choosing from among them in the course of their research and the development of their expertise. These *spaces of interaction* provide a profile to which 'experts' can contribute, or can participate in, and can in turn provide markers for the boundary work of scientists' disciplinary identities. This seems to be done not purely in a disciplinary manner, even though these sources might carry denominations of a disciplinary nature. Instead, the accounts of my respondents suggest that interaction takes a pinpointed approach orientated along research interests and research areas or fields, in a way copying the configuration of the researcher's specialisation and skills. Thus, the sources of information for research are less disciplinary in their practical nature, although they might be referred to as disciplinary sources and still provide a disciplinary home for publishing or institutional affiliation.

> **Researcher17**: “You would tend to do a search on a subject. [...] Because a lot of nano-relevant research goes on in a more mainstream biotechnology kind of area. So, it'll get published in different sorts of journals.

> **Researcher18**: “There are quite a few [conferences] in the field [...] but I try to go to those which are covering [my research]. Then I'm trying to go to those which cover surface science because they are mostly becoming [...] nanotechnology.”

Indeed, practical considerations seem to rule the choice of sources as much as wider interests in a specific discipline or research field. However, as I mentioned above, the reference to disciplines strikes me as being something of a reflex or even an anchor. This seems to fulfil two identification tasks. Firstly, as a way of providing a starting point, or a common ground, as a safety net and disciplinary home. And, secondly, as a point of return, to report in an environment (for example biology) in which one has been socialised and whose scripts and (narrative) accounts might be more familiar than those in the research field (biotechnology) or project work (bio-sensors). The scripts might even extend into or influence these spaces and thus appear discipline-contingent. Apparently, this applies to both academic and industrial researchers, as a significant number of my respondents had been working in the industrial sector before coming (back) to research in academia.

> **Researcher20**: “And also more discipline-specific journals, which tend to publish a lot of related material such as Physical Review, and Physical Review Letters and the Surface Science, Journal of [the] American Chemical Society. So, I think it's important, because of the blurry edges, the interdisciplinary nature of the area, it's important to look at a [...] wide range of different journals in order to be able to follow what's going on [...].”

> **Researcher21**: “The general physics journals, mostly applied physics-journals: Applied Physics Letters, general Applied Physics, Nature, Science, the Institute of Physics publications. I do just a general search, and they are the sort of places [that] publish the work that is relevant to my particular area. [...] I publish in Nature Materials myself. People in my field published in Nature Material and Nature Physics, so it's more where the physics are.”

Thus, the *practical* and the *structural* (or *belonging*) dimensions of disciplinary identity are present again and more directly communicated in the choice of journals and conferences. However, these are just two, albeit extremely significant, sources for researchers. Other important sources are embedded in project collaboration, namely as in-project reports and external expertise connecting to own expertise. I distinguish between these two as they can have rather different contact points and qualities.

*Strategy Dimension in Research Sources*

Research information gained from reports of projects can result in a widening of the scope and understanding of peripheral aspects of individual research, or even further, provide a wider context to research in general.

> **Researcher12**: “It's very easy to stay informed [...] because the projects we are working on now are generating a lot of [...] information, a lot of e-mails, a lot of reports, a lot of market studies, a lot of technology studies. [...] I'm reading reports and reading, you know, studies of markets and reading state-of-the-art documents, I'm reading policy documents, all produced by projects which are running.”

Expertise of other scientists, however, can connect to one's own in a more personalised and directly negotiable manner. This can take place within collaborations, for instance in seminars or work-package meetings, but also during scoping initiatives and in fora. This 'foreign' expertise can not only provide information on current or on-going projects, but help establish connections to potential partners for later projects. It might even influence the trajectory research interests might follow through furthering the understanding of different perspectives on the research area or field. In a way, this could also be interpreted as contributing to the construction of the *strategy* (or *potential*) dimension of research identity. Respondents have referred to foreign expertise in comparative ways.

> **Researcher16**: “[T]alk to collaborators and see what they think is important, whether they are academic collaborators or industrial. They both have a very different view on what we do and the world in general. Go and talk to find out what they want us to try to pull off.”

The presentation of which sources – informing and influencing research interests – are used, and how this choice is rationalised, is part of the boundary work of researchers. The three dimensions of identity that I developed in the first part of this chapter are reflected here. Further aspects also have influence on the choice of spaces of interaction, such as time-constraints, system requirements and scripts. These are practical expressions of the structure of science and thus indirectly influence the construction of an overarching research identity.

## 5 Division of Research Labour

Research responsibilities and seniority in identity construction

Scientists also construct their research identity through the description of their research tasks and responsibilities. These social constructions regard agency as another element of identity, and allow researchers to position themselves within the hierarchy of science. The actual agency differs according to certain premises and allows for certain tasks or responsibilities, which, again, can have a wider effect on the institution of science.

*Research Tasks: Content and Structure*

The generation of data might be considered a vital aspect in research, but the division of labour allows for a broader understanding of research agency. There is a strong tendency in the accounts of my respondents that a scientist's routine as researcher is not based on the generation or collection of raw data in the *laboratory* as a defining exercise. Instead, active participation in the social structures of science dominates, either in a wider understanding of research or in a structure-perpetuating capacity as manager or teacher of science. In regard to their research tasks, then, I suggest two poles in this continuum of research agency, (1) the *content-generating* or *lab-based* and (2) the *structure-perpetuating* or *managerial* scientist. The distinction between these two types rests on different foci of tasks and responsibilities in the process of knowledge production, and thus also on the diverse professional relationships to actors inside and outside of the laboratory, school, faculty or university. With this distinction, the element of seniority is raised as research tasks and responsibilities change with the development of experience, expertise and more defined accounts such as publications, presentations and institutional positions.

> **Researcher7**: "[I] write proposals, get my own funding, supervise students [...] At the moment I don't do any teaching or lecturing. But the idea is, over the five years for the teaching mode to increase. So, at the end of five years, you're teaching as if you were a lecturer."

> **Researcher20**: "My job is effectively to undertake research in the area of nanotechnology within my department, and also to be involved in the teaching in the

> Physics department. And this then leads on to a permanent position, sort of a lecturer's position or similar. The ration of teaching-to-research changes a little and becomes a little more teaching and a little less research."

Generally, junior scientists such as postgraduate and postdoctoral researchers and research assistants belong to the first category. Also a significant number of mid-stage researchers spend a critical amount of their time in the 'laboratory' (or office), depending on their research. Research tasks and responsibilities include the generation of data and writing papers. For mid-stage researchers the amount increases to also encompass seeking out funding, and the aspect of habituation (cf. Bourdieu, 1987) or socialisation of junior researchers both in lecturing/teaching and in supervision. Supervising students also encompasses shared management of research.

> **Researcher18**: "My job title is Reader [...]. And I'm doing research and teaching. [...] I'm in [the] laboratory, I'm an experimentalist."

More senior mid-stage and senior researchers tend to be less occupied with the collection of raw data, but share most of the other tasks. Their work load can consist of extended lecturing, management of research projects and getting involved with the administration on an institutional dimension. Thus, their focus is both on dealing with the content of research as well as perpetuating and developing the structure of research.

> **Researcher14**: "It's changed a lot. I mean, since I am now in a management position [...] I don't have so much time to go to the lab. I do try to go to the lab. I will see my students and discuss at least once a week for an hour. I will read and do some modelling-work, I have to do that on trips and things. Tend to use students to generate the data and then I get involved in the interpretation and understanding side."

> **Researcher19**: "I'm mainly doing paperwork in the office. Since becoming a lecturer I've had very little time in the lab. [...] It's mainly administration, trying to do grant proposals, getting lecture notes ready, supervising projects. [...] There's a lot of teaching aspects and general admin[istration] aspects that are sort of generic [...] your everyday university duties. And wherever I can fit in [laughs] lab-time or looking at journals, that kind."

> **Researcher24**: “At the moment, my job description is project manager, essentially. I still have some responsibilities for doing bench-based lab-work. I have responsibilities for the running of the bio-lab [...]. And on top of that I've got objectives to meet in terms of actually preparing proposals and bringing research-based work to [the institute]. The majority of my time, as I said, is spent either in the lab or project-managing [...]. And at the moment I'm putting a lot of effort into writing Framework 7 proposals [...].”

The perpetuation of the structural dimension of science seems to be the stronger aspect in the work load of more senior scientists. It can be interpreted as the more effectual aspect in regard to the on-going institutionalisation processes in science (for institutionalisation processes in organisations in general see for example DiMaggio and Powell, 1991; Hasse and Krücken, 2005). These processes take place in every-day practice, both in content and structural work. They can be formed more directly by senior researchers since their institutional account, for instance their track record, and scripts of conduct will favour the input from their expertise and preferences in what could be described as the *ancien régime* of science, the precedence of established structures in science governance.

> **Researcher27**: “But I also have a responsibility for the research direction and the management of the institute. [...] I don't do very much teaching. [...] But then there is the institute role, which is quite a substantial role. It's looking out for the growth, the development, the health of the institute, and those areas. [...] These days, sort of in the role that I have at the moment, I'm much more a kind of research leader in the sense of [...] having the ideas for projects, writing the funding applications, supervising the work. [...] It's very unusual now that I actually [...] find the time to be able to do the work myself, which is frustrating sometimes but [...] it's a fact of life with, sort of, increasing seniority, really.”

Managerial scientists take on primarily communicative and administrative tasks: setting up and administrating research institutions such as research centres, schools, faculties, but also research projects. Within collaborations, be these workshops, projects or initiatives, the managerial scientist becomes an intermediary or “rapporteur” (Researcher15), thus becoming far more aware of issues, results, context and outlook than other collaborative partners.

> **Researcher12**: "[T]here is liaison with other members of the group, which are in different disciplines: engineers, the chemists, the clinicians. There is always, you know, preparation of papers, submission of papers for publication; looking at ideas for new funding opportunities, new grants, pursuing new avenues with other collaborators. So, I suppose it's much more of an administration, management and forward-looking role than [...] hands-on delivery [...]."

> **Anonymised Researcher D**: "I was [involved with] a grant, which was awarded from the MRC as an institutional discipline-bridging award. So, for three years my role was a facilitator to bring medicine and nanotechnology closer together. Not project-specific."

*Spheres of Science*

Thus, managerial scientists collaborate within what I conceptualise as the *sphere of research* (content-generating) as much as they communicate with and, outside of research, within the *sphere of governance* (structure and policy), which influences the way every-day research is conducted. Writing grant applications, lobbying and providing expertise in the process of regulation as well as refereeing in processes of grant applications are all aspects of the process of legitimising research. They provide the elements for understanding the two spheres of research and governance as overlapping and interdependent. These responsibilities allow for scientists to leave the (protected) lab-space but remain researchers, whilst they commit time for tasks not entirely focused on their respective research area. Subsequently, they function as communicators – or interpreters – between lab-based researchers and expectations, requirements and support from the sphere of governance (cf. Deuten and Rip, 2000).

> **Researcher15**: "I'm director of [a nanotechnology institute], and within that the institute has a number of... themes. One's research, another is using the details of that research for outreach, that's consultancy."

In summary, the range of activities that are subsumed under what my interview partners describe as their research tasks characterises the routines that are part of their research identities on a secondary level. There are no obvious disciplinary differences regarding the structure of tasks and responsibilities, although they might differ in content. Instead, experience and expertise play a significant role in the individual localisation within the hierarchy of science, thus adding another perspective to understanding both the *structural* and the *practical* dimension of identity. Here, the focus lies on differing agency between *content-generating* and *structure-perpetuating* scientists. In fact, the division of labour, and therefore agency, might be considered as having a not insignificant level of influence on how the emergence of research areas or fields, or even disciplines, might be considered by the researcher.

In these previous sections I presented an understanding of how scientists construct their identity through research practice: the elements contributing to identity, and the motivations to pursue certain trajectories within these elements. Science as a social structure provides the scripts for scientists to negotiate and renegotiate their identities: from disciplinary training via research interests to ongoing research; through science policy; along increasing track records and seniority; and through a shift in tasks and responsibilities. The most interesting aspect for my analysis are the first two elements, the combination of disciplinary background, research interests and requirements mainly communicated by science policy and its effects on funding strategies. In the following sections I examine how these elements operate in relation to NST.

# 6 Researchers' Perceptions of NST

Scientists' perception of NST as an element of science and science governance

The understanding of Nanoscale Science and Technology (or *technologies*, as pointed out by one of my interviewees, a director of an NST research institute) varies greatly between individual researchers. Indeed, 'nanotechnology' or 'nanoscience' as concepts are considered less in practical terms by some, whereas others define their research in these terms very strongly.

*Understanding NST and its Terms*

Already the distinction between the two terms is at times blurred, or even considered irrelevant as the thrust of nanotechnology is invariably bound to the understanding of behavioral idiosyncrasies of matter at the nanoscale. In addition to that, this understanding seems to be provided already by canonical (sub-)disciplines such as quantum physics and colloid chemistry. However, a strong understanding seems to prevail that the direction and context that nanotechnological applications might be used in provide a good enough framework that might defeat the purpose of distinguishing between nanotechnology or nanoscience.

> **Researcher17** (clinical scientist): “I don't know if there is a difference, is there? I don't know what the word 'nanoscience' means. I have no definition for that, it's not a term I use. [I mostly use] nanomedicine.”

On the other hand, the field of NST can also be seen as a framework providing orientation or common aims, resulting in making a clearer distinction both for the field of activity of individual researchers as well as bridging diverse research to scope and explore further possibilities. NST could thus help in developing other research areas.

> **Researcher21**: “Within the physics department, we have a 'nanoscale science technology group'. But beyond that, within the Department, there are other people working on materials and structures and behaviour where [...] the nanoscale regime is important. And therefore you'd put that into the regime of nanoscience and nanotechnology. So, there are many, many people in this department who work on that.”

However, in at least two aspects NST is perceived similarly by all my respondents. Scale is seen as a defining element, and the understanding of NST is considered to be very broad. In fact, it is described as being so broad that to refer to the terms nanoscience and nanotechnology (or 'nanomedicine' for that matter) in every-day research activities, especially in the generation and interpretation of data, but also in the communication of research processes and results, is regarded by many as being of limited utility. Very diverse research takes place at the nanoscale and might not necessarily or easily be connected across all epistemologies and methodologies.

> **Researcher16**: “There are aspects of what we do that can be classified as nanotechnology. It depends on the view that you have of nanotechnology. Whether you see it as the bottom-up construction of free-standing and self-organising [structures]. Or whether you just say 'it's something that's smaller than 100 nanometres', where you're actually playing with the parameters of something that's smaller than 100 nanometres. So it depends on whose description of nanotechnology you use. [...] It covers everything. I have a friend who does nanotechnology in concrete. There, you can't get much more of a

> brain-bender then that. [...] You have people doing carbon-nano tube research and bottom-up fabrication where the things are self-aligning and building themselves. [...] you got biology on one end and civil engineering at the other. And everybody else is running around the middle. So, I think the actual description of nanotechnology is usually left to people who are running around on the inside."

*Sources for Understanding NST*

There are two major sources to the understanding of NST: the personal perspective as a scientist, and external requirements from the structure of science and from differing elements of society. The former represents the internal approach, drawing on disciplinary considerations and practical expertise. The latter informs the construction of how external influences form an understanding of NST, which is mostly portrayed in a more critical light. Here I shall look at the requirements as perceived from a scientific point of view, whereas in chapter 6 I look at scientists' perceptions of the non-academic and non-scientific aspects of NST.

In scientific constructions, the intentional aspect of working at the nanoscale seems to be one of the less controversial elements: manipulating, building, structuring, scaffolding. It relates the field closely to engineering, and the pursuit of research in this area to applications in the real world. Thus, research and developments in NST are embedded in an existing world of science and technologies as something that will further understanding and utilisation of materials and technologies for improved applications. The very novel aspect, expressed in the enabling and disruptive nature of NST and its endless range of applications (cf. Drexler, 1990; Kurzweil, 1990; Roco and Sims Bainbridge, 2001) features rarely. Rather, it is challenged, or at least less defined in the accounts given by my respondents. Therefore, different understandings of NST can be found empirically from the portraying of scientific descriptions of the field in comparison to the existing literature. The individual approach is based on researchers' specialisations, on their expertise and disciplinary background.

> **Researcher11**: "Nanotechnology, in my context, nanoscience also, is basically the understanding at a nano-level, the physical phenomena that occur. It's not necessarily intended towards the miniaturization of the device, which I think is being done by other people. It's more the application of nanoscience for a better understanding of what is

> actually going on at that level."
>
> **Researcher12**: "[T]o me nanotechnology is manipulating things on nanometre scale. You know, building structures [...] atom by atom and molecule by molecule. Building functional biological devices using natural assembly processes to create different types of [...] activity, or different types of action, but... there is no way that nanotechnology as such is an independent technology, it's a dependent technology on everything else. So, anything from, you know, sunscreens and drug delivery systems to molecular machines have to be supported by the world around you [...]. What you're doing is exploiting properties at the nanoscale from macro or micro scale objects."

*Development Level of NST*

The epistemological nature of the field remains vague as many canonical (sub-)disciplines seem to make claims on the investigation and exploitation of the nanoscale. Also, existing technologies are considered to be essential for the application of nanotechnologies in the real world. Therefore, NST takes on the form of an emergent feature of existing approaches to the world in science and technology, even though some of these accounts might follow the more visionary understandings of NST, as in "molecular manufacturing" (Researcher22). I examine the epistemological nature of NST more closely in the next section.

Research relating to NST is considered on a qualitative level, including a temporal dimension, that connects to its embeddedness in the existing frameworks of science and technology.

> **Researcher19**: "Anything that's manufactured at that level is essentially nanotechnology [...] the sort of engineering at that level. [The] surface chemistry [...] that's sort of the nanotechnology side of [biosensors]."

Nanotechnology is mostly seen as being in the early to medium stages of both interest and development, where most of its deliveries remain 'soft technology' and are deeply embedded in existing technologies and epistemologies. According to calculations from February 2008, over 600 current consumer products on the US-market include some kind of nanotechnology (Woodrow Wilson International Center for Scholars, www.nanotechproject.org), probably mostly in particle-form. Some of my respondents mention products such as tennis rackets or window panes as including nanotechnology, but believe that these are not the 'real nanotechnology' that is still to come. In fact, most 'consumer nanotechnology' today is found in health and lifestyle products, and as such in luxury goods. The nano-divide of access to nanotechnology becomes visible here. Despite an understanding of the field as being mainly part of an incremental development, expectations of research leading to more profound, 'hard' nanotechnologies also exist.

> **Researcher14**: “A lot of what people call nanotechnology I would still call nanoscience. I don't think there is very much nanotechnology that's actually a true technology. There is an awful lot of science that's being done.”

> **Researcher16**: “There is the possibility to do things very, very differently. And I think that this is one of the exciting areas. There are opportunities for things to be done. In completely different ways. However, at the moment I think people are really concentrating on doing more of the same. And looking at the [possibilities], thinking 'can we do them, is that actually what we should be doing?'. I think people actually have to look at that area more and more with a view to doing it. But I don't think they actually have yet.”

> **Researcher24**: “A lot of what people talk about as nanotechnology is actually microscale rather than nanoscale. But I think there are some novel and new stuff and the understanding that this is about a nanoscale-thing rather than a nanotechnology-thing.”

*NST and Science Governance*

Understandings of NST apparently focus on utilising the terms in economically or politically advantageous ways, especially when considering science policy. Opportunities of funding and reactions to those, such as re-labelling research projects and institutions, are reflected in a slightly critical understanding of NST. I elaborate on this in the next section of this chapter as this development has apparently also had a significant influence on how researchers who could be considered doing research in NST construct their research and their research identity in relation to NST. Here, I look at the way external understandings of NST, especially the funding-aspect of it, have influenced scientists' uptake of NST.

Governance organisations play a vital role in today's research funding. The communication between the research sphere and the funding and regulating bodies impacts on how both sides view the research area or field they are negotiating. Elements of progress and conducting cutting-edge research seem to be communicated from both sides and mark the use of terms of NST as something that is related to attempts of gaining funding and attention.

> **Researcher14**: "But there are [many] people who want to use 'nano' because it's the sexy term. And the funding proposals, and people who are doing work, which isn't really 'nano', will call it 'nano' because they want to... appear to be modern and exploiting the latest trends and all those sort of things like that."

Following from this evaluation of how 'nano' is utilised, it might not be surprising that for some of my respondents the way the emerging field of nanoscale research has been approached, shows a lack of scientific understanding and developmental strategy. Thus, it results in a less institutionalised approach to NST and in re-labelling existing research without necessarily supporting the emergence of 'real' nanotechnology research projects.

> **Researcher12**: "I'm not sure [the Research Councils] know exactly what they mean by 'nanotechnology' and what they want to support in the area. I think they want to see, by using the terms and by putting them up as 'flagship' priority areas, they're trying a kind of fishing exercise: [...] 'what kind of research applications would we get in from the community if we make this a priority area?' What is the community thinking, and then helping to inform them and change the policy slightly, and change the priority areas slightly. I don't think, internally they really knew what they were doing, and what to expect from what they said. I think they're using the community to inform them by looking at what the community produces, proposals."

In this quotation, the researcher refers to 'the community' several times. However, other passages in this interview do not lend reason to understand this community as an NST-focused one. Instead, this reference appears to describe a number of academic researchers – whether in a certain regional setting or beyond – as a kinship group, unified in their interest in research and the impacts of their research on others. It does reign in with a permeating 'us-versus-them' attitude in other respondents' considerations of science funding bodies. This might have to do with demarcation efforts of what is science in NST, and what is not (see the section on *NST* *and Research Identity*; but also *Scientists on Non-Scientific Aspects in Research* in chapter 6).

> **Researcher21**: “Many of these [funding organisations] don't have a clear understanding of what nanotechnology is. Some of the universities [...] in the region have taken advantage of that and taken some money off them, but not in any really strong organised way.”

> **Researcher26**: “I would imagine there is an agenda within [the] Faculty [...] to badge or brand with that kind of nanoscale or nanotechnology label. It would fit within the remit of funding councils, they support that work. Clearly, there is funding associated with [the] Life Science-Nano interface.”

Two of the researchers I talked with pointed out very different experiences with that approach of funding bodies. One contemplated funding streams having directed the institute and him as its director into the field of NST (Researcher15). The other researcher showed disappointment by the way nanoscale research was almost misused as a label in research proposals. In his view, this resulted in funding being granted to only a limited number of research projects, which didn't necessarily advance any genuine nanotechnology research (Researcher20). Whereas Researcher15's focus on NST follows funding policy, Researcher20 has been engaged with NST before, thus has developed an understanding of the field that was not met by the funding policy applied in that case.

*Regional Idiosyncrasies Embedded*

Indeed, a picture emerges of nanoscale research being embraced only in a limited way in my case study of the North-East. This could also have an impact on the way research identity is constructed, that is to fit in with local or regional requirements, or scripts of approaching certain research fields. In addition, experiences with the emerging field, either personally or institutionally, can influence the attitude and thus the extent of identification with NST. Respondents' accounts suggest that science policy from institutions and individual research strategies from peers have influenced their views on NST.

However, collaborations beyond the local and regional level also show impacts as the field seems to be strongly embraced nationally and internationally, with more numerous and active research institutions, such as research centres, journals, degree programmes, research activities under the umbrella of NST in general. National and international projects and networks, in which individual researchers from the North-East are integrated, foster the persisting interest in conducting nanoscale research.

> **Researcher17**: “There's more of a European identity to 'nanomedicine' than there is a [University] one. It's been an easier thing to get. [...] We're having a summer school on it, but it's gonna be in Cardiff, funded by the European Science Foundation again, so they kind of like the subject. And a lot of European people like the subject as part of Framework 7, but in terms of the way [the University] looks at it, it's not being a word used.”

> **Researcher18**: “I don't think anyone in Britain has [an undergraduate course in NST], because nobody is *brave* enough. Well, [there are] people that were brave enough in Sussex, and Australia, in Australia it works. They have a full course there. So, it's possible. But at the moment [the University] doesn't have [one]. You need a critical mass of people [to] teach. [...] And because you don't have a department, so you have to get from every school a few teachers to teach such an undergraduate course.” (emphasis added)

In this section I suggest that scientists doing nanoscale research are influenced in their understanding of NST by two major sources: by their disciplinary background and scientific experiences, and by science policy, for example funding. They paint a picture of very varied understandings of nanoscale research and potentials, but generally one that allows for the inclusion of the field in other research areas to a certain and adapted extent. I propose that the connection of the different elements of researchers' identities with shifting research and governance requirements becomes apparent. As Researcher18 ventures, it still takes *bravery* to commit fully to NST, implying that the field is not fully accepted in academia.

## 7 NST and Research Identity

Relational narratives; demarcation, sceptical distancing or framework NST as specialisation

Four marking points within a continuum of affiliation with nanotechnology and/or nanoscience have emerged from the accounts of my respondents regarding their research.

First, a small number of researchers have expressed their interest in nanoscale research by considering that it might become a field they could work in. This may seem a little at odds with my choice of respondents, but actually emphasises the apprehensive approach to NST that seems to be prevalent among a large proportion of the researchers I have talked with. They might be part of an institutionalisation in that field: a network, a research institute, a project; but they do not necessarily find that NST defines their research (much).

Here is where the second marker comes in: the majority of researchers I talked with have acknowledged that a certain element of nanotechnology or nanoscience features in their research. The nature of that element varies quite significantly, shedding a bright light on the different epistemological understandings of NST, of which there are two strong understandings: the more conservative more-of-the-same-just-smaller and the bolder not-just-miniaturization position.

Third, activities in the field of NST are expanded and can take on a focus on nanoscale research and/or teaching of nanotechnology, nanoscience, nanomaterials and so forth. Again, the different foci provide a certain diversified uptake of NST and its meanings in the identity work.

Fourth, researchers place their research within the field of NST. Although their *belonging* identity might not be nano-related, their *practice* identity is very much immersed with references to research being focused on the nanoscale. This influences the epistemological outlook of their disciplinary background.

Generally, then, researchers relate to NST as something they can connect with, but for only a very small number among my respondents has nanoscale-research actually become something like a framework, a strong focus in their research life. The four marking points describe in how much NST is an element of the research identity the researchers construct. The focus of the analysis in this section lies on the consideration of NST in relation to scientists' on-going or future research, not so much their view on what NST actually is or can be, which I looked at in the previous section.

*Critical Distancing*

A certain careful critical distance can be traced throughout the accounts of many of the researchers I have interviewed. NST is often negotiated in a distancing way when relating the field to their work, as being something of interest and of potential utility for their research, but not necessarily as something they would label their research as. Instead, the majority refers to it as aspects or tangents of on-going research, mostly covering aspects at the nanoscale rather than actual nanotechnology.

> **Researcher8**: "[My research] is encroaching on it, [...] it's not in the centre of nanotechnology, but we are constantly dealing with those kinds of dimensions in one aspect or another. Movements of some nanometre-movements, we're having to sense those movements [...]. And the designs that we get involved with usually requires us to take account of those sort of dimensions [...] in order to get the accuracy [...]."

> **Researcher12**: "[W]e are working with pushing molecules onto surfaces of devices in an orientated, controlled, patterned fashion, so the dimensions of those molecules are in the nanoscale, and the dimensions of the devices we are putting them on are in the micro- or macro-scale. So, individually nanotechnology: no. Nanotechnology to support microtechnology, to support macro-technology: yeah, possibly. But the very... the real understanding of nanotechnology: no, we're not. We're using basic biochemistry."

> **Researcher16**: "I have a physics background, I work in, you know, the electronics, electrical engineering, there's obviously some material science in what I do, some aspects in nanotechnology what I do [...] It's the control of things that are very, very small."

Here, the dimension of *strategy* comes into play at most, rendering NST as something at the outer periphery of identity. On the level of understanding, the aspect of 'nano' they have considered remains as a conservative element confined to scale, mainly due to the material nature of their research. The 'real' nanotechnology that has been mentioned refers to the different natures of NST. Indeed, the *strategy* dimension in combination especially with the *practice* one can be found in the display and construction of the underlying epistemology of NST. Before I elaborate on that aspect, I briefly examine how NST enters considerations of *practice* and thus of every-day research activity.

Nanoscale research features prominently in the *practice* dimension of accounts of any of my respondents, which was to be expected. It covers the wide range from contributing aspects to teaching or studying the field under the names of nanoscience or nanotechnology.

*Sources of Personal Affiliation with NST*

The personal approach to the nano-aspect of research is described in three ways. First, as something one has explicitly chosen to pursue, as a personal choice. This choice is connected to either necessity (such as for medical applications), because of funding-streams, or because research interests focus on the atomic or molecular level generally. Second, the personal connection is explained in terms of having emerged from previous research, in way of an incremental evolution. Third, external requirements have influenced the personal choice, either in responding to requirements from practitioners/industry, or strategy-dependent in exploiting funding streams, mostly in context of the competitive nature of academic and industrial research. The distinction between the three approaches is sometimes difficult to make, also because researchers tend to move between the poles in their accounts. Generally, researchers seem to view their relation to NST as a result of an internal inertia of research, as following a trajectory in their research that leads to the nanoscale.

The three quotations below illustrate the diverse personal approaches. The first quotation seems to be an example of (1) choice as the researcher seems to understand his move into NST as a way of improving applications in patient treatment.

> **Researcher11**: “My current workplace is involved in nanotechnology and nanoscience in respect of understanding the potential uses of these new sciences in two respects: number one is to understand the way that nanotechnology and nanoscience can be applied to a membrane, to make the membrane more selective, to make the membrane more bio-compatible. In addition to that, I've also got an interest through collaborations with other groups in developing new meso/micro/nano-porous materials [...]. And thirdly, there is also an interest in using nanoscale devices to facilitate mass-transport.”

The second quotation exemplifies the position of (2) an incremental evolution towards the nano-scale, following personal interest but driven by the inertia of research.

> **Researcher14**: "As time's gone by, the coatings and the applications that I've become interested in have gotten smaller and smaller, and thinner and thinner. So, that's how you go into the nano-area."

In the third quotation, the director of a nanotechnology institute reflects on external input, in this case funding, that has influenced the focus of his research institute and thus his research interests.

> **Researcher8**: "Some benefited from finance that was initially available [...] to start projects off. Which is very good because that's usually a big stumbling block with any ideas [...]."

Whereas the elements of *practice* and *strategy* are illustrated in most of the accounts on NST and individual research, no-one regards the field in the way of contributing strongly to their *structure* identity. However, in a few cases the institutional dimension or context of their research, being part of an NST-organisation (research centre, institute, network), seems to be influential on how researchers constitute their identity in regard to NST.

> **Researcher2**: "No, [because] I am not a PhD-student of the Institute of Nanoscale Science and Technology [...]. I don't work with purely technical features in characteristics, I don't fabricate nano-devices or nano-chips or anything like that. So, that's why I don't feel that I'm doing pure nanotechnology."

Also, those researchers that focus on elements within the field of NST, adapting it almost as their new framework, tend to see nanoscience and/or nanotechnology as disciplinary entities that contribute to the understanding of their research as much as physics or chemistry do. In these cases, the *structure* identity does feature to a certain degree in individual affiliation with NST.

> **Researcher18**: "I have researched maybe in three or four areas, and mostly they are in nanotechnology, or nanoparticles. [...] one is on silicon nano-crystals, which I'm collaborating [on] with people from natural sciences [...], another area is working on nanomaterials [...]."

> **Researcher20**: “Effectively, [my research has] evolved. The area, in which I carried out my research, was surface science, but I started off looking at [objects at the nanoscale]. So, I was already effectively working in an area closely related to nanoscience. [...] Yes, I guess that would be the best term to use [to describe the field I'm working in]. I think physics is a bit narrow because some of the stuff that I've been working with probably crosses over into chemistry. [...] I don't think there's this rigid definition between physics, chemistry, biology, engineering etcetera.”

A slight distancing remains. This is probably due to the way NST is perceived epistemologically by researchers. Their perceptions at times contrast starkly with the views that individual proponents of nanotechnology (cf. Drexler, 1990; Freitas, 1999; Roco and Sims Bainbridge, 2001) and institutions such as the Foresight Institute and the US National Nanotechnology Initiative (NNI) have formed on nanotechnology. These have been described as being either utopian or dystopian, Science Fiction or imaginary.

> **Researcher11**: “I think there are people in nanosciences... can be divided into two groups to my mind: there are those people that talk about it and there is those people that do it. And people that talk about it often have a different comprehension because they are talking very much of a broad-brush strategy whereas the people that are doing it are look... are focusing on practical issues and practical problems associated with it.”

> **Researcher17**: “[Nanotechnology] calls on so many things, both real and imagined, [...] and people are using it as a sort of infinity. [...] They are not being very realistic. So, there's a real end, and then there is an infinity end, which is more fiction.

*'Preliminary' and 'Real' Nanotechnology*

Two junior researchers and some of the medium stage scientists in my respondent group feel that the highly visionary works of Eric Drexler and Ray Kurzweil have sparked the popular imagination of NST, thus helping to socially construct the field and open up funding sources. In their research accounts, as in the accounts of very critical researchers, however, the understanding of nanotechnology is more practical and focuses on two approaches: (1) a “preliminary” (Researcher23) or (2) a “genuine” (Researcher14) and “real” (Researcher12) understanding of nanotechnology .

*Preliminary nanotechnology* describes research that is generally relying on techniques and understandings of matter generated by the canonical sciences, for example looking at the physical properties and characteristics of matter at the nanoscale, or using lithography and optical techniques to work at this scale. Miniaturization is a key concept here, possibly also towards the future *real* nanotechnology. It is very much the understanding of the *top-down* approach, focused on the contribution of physics and areas of engineering, and connects to the evolutionary narrative of incremental advance in science and technology.

> **Researcher11**: “It means that the electronics are smaller then when you had valves, but the functionality is probably pretty much the same. [...] I think it's a question of whether you believe that nanotechnology works from top-down or bottom-up. [..] I am of the opinion that it works from top-down, rather than bottom-up. I think that there are some people that believe that nanotechnology can solve your problem, but that problem is basically a problem that can be expanded and enlarged and appears in other areas, and, basically, what you are saying is 'I can bring it down to a molecular level to try and solve [...] that problem'. You know, whether you have carbon nanotubes or whether you have a porous material made out of ceramics really doesn't matter, the fundamental concepts within that remain much the same. The scale is the only thing that dissolves that.”

The quotation above is one of the more polarising ones, implying that there is no need and possibly no potential for the emergence of a new epistemological approach as the concept of *bottom-up* is rejected. Commonly, many respondents feel that at the moment the majority of research in NST remains at the *top-down* level and the development of new understandings and techniques is on-going and still to come.

However, the understanding of *real nanotechnology* is connected to *bottom-up* approaches. Science and technology will accomplish things differently at the nano-level that cannot be done at the micro- or macro-level, or have not been done previously at the nanoscale. Here the development and utilisation of new approaches and understandings is seen as a key point to nanotechnology. Contributions seem to focus more on quantum research, chemistry and biology.

> **Researcher14**: "[A] lot of the technology is arising because of the [change] of the science. You know, if things work the same way in large scale all the way down to small scale and there was no change in mechanism, no change in the science, then nanotechnology wouldn't exist as a discipline. The fact is that things change when you get small."

Still, when researchers refer to aspects of their research being nanotechnological, they often do so by comparing it or referring to techniques from other areas or disciplines, almost in a *paradisciplinary* way (cf. Wienroth, forthcoming). They refer to NST as being a multi- or interdisciplinary field of jointly contributing or even converging sciences and technologies, and as something that has emerged from or through their on-going research. Independently of whether the field is seen as a new discipline or not, it is often described as a field of research and application where methods, techniques, skills and knowledge from different disciplines and areas contribute to the format of research in NST. Thus, knowledge and technologies are produced that could not be created by just one discipline. Only one researcher, a physicist, argues that his core research takes place within the disciplinary boundaries of physics, but still expects that the development of applications will require collaboration with researchers from different backgrounds, in this case medical scientists.

*Demarcating Science and Fiction*

I have mentioned before that the apprehensive approach to affiliating with NST is probably due to the view that nanoscience and especially nanotechnology as concepts have been 'muddied' with overly visionary expectations that are considered to be less scientific, even outright utopian. It would appear that conducting research in NST is very much connected to the need to legitimise one's own research, almost like constructing a credibility that the term 'nanotechnology' seems to lack. Content-wise, NST research is required to take place at the nanoscale and deal with the special properties there, and the control and manipulation of objects and structures. The methodological approach needs to be based on existing research, stick to what is possible at the moment and take it from there. In fact, researchers who have been affiliated with institutional settings of NST (initiatives, projects, grants) apparently find it necessary to demarcate what they consider to be Science Fiction or even "apocalyptic" (Researcher14) from what they consider to be 'real' or 'solid' science. This aspect of demarcation signatures boundary work, endogenously legitimising one's own socio-technological world by referring to terms and concepts of NST as boundary objects instead of canon. They do so by referring to external notions of nanotechnology or nanoscience, negotiating scientific terms of NST in regard to their extrapolation in the public domain. Thus, non-scientific aspects enter the discussion and have prompted said critical distancing of researchers not just to extrapolations but also to the use of nanotechnology and nanoscience to characterise their research.

> **Researcher20**: "[Y]ou've got a whole spectrum of use from people who, perhaps, have rather wild ideas of what can be achieved, and, generally, that people, perhaps with less scientific credibility perhaps, are working directly in the area. And then, actual real sort of practical outcomes in terms of both science and technology. [...] I thought [the Drexler-Smalley debate] was very interesting. [It] summarises the sort of rather utopian, or, well, dystopian in some cases, [...] science fiction type vision of what's possible, and perhaps something that's grounded more in reality. But if you look at the reality, it's already so exciting you don't need this, in my opinion, don't need the science fiction type [...] machines going around and self-replicating, and going inside the human body to repair things, because already what is potentially possible, based on solid science, is exciting enough."

The expectations and promises of nanotechnology, the processes of lobbying and distributing visions that have contributed to constructing the entity NST in the public domain, that have generated policy interests and thus helped open up funding sources for NST research, are the same processes that make researchers wary of the field. To refer to nanoscience or nanotechnology is perceived as impractical in terms of every-day scientific research because the terms encompass too many areas of interest and application. The only common attribute, the lowest common denominator, seems to be the scale and its special properties. NST is seen with mixed feelings also because it carries the quality of a label to opportunistically re-brand on-going research that still lacks the qualities of *real* nanotechnology. These political aspects of science are perceived as un-scientific, or not part of the sciences.

## 8 Disciplinarity in the Construction of NST

Recurring to traditional disciplines, trying to fit NST into existing frameworks

As I have pointed out above, researchers working on aspects of NST refer to different disciplinary backgrounds and areas of enquiry when talking about nanotechnology and nanoscience. Both areas are perceived and contextualised as drawing on and emerging from existing disciplines and areas. They connect to these and other fields of technology. Researchers collaborating on projects featuring nanotechnological or nanoscientific aspects see new opportunities for enquiry and application due to the scale and quantum mechanics. At the same time, they accumulate or adapt their knowledge and/or skills through exchanges with colleagues from other research backgrounds.

> **Researcher15**: “[T]here may be people who have come to that as chemists, or biologists. And they bring to the party their concepts, and there is almost a clash of culture between physicists and chemists and engineers. And that's [a] crunch-point, where new opportunities will exist.”

That does not necessarily mean that those researchers feel they are working in a different or new environment to their own background. On the contrary, whilst some may perceive the level of research they are conducting as NST, others perceive it as an aspect of their disciplinary background with input from other areas. This can lead to researchers wondering where exactly they can situate themselves on the map of disciplines, and to renegotiating their understanding in the *practice* and *strategy* dimensions of their identity. This implies an understanding of NST as a layer, as a 'tool-box' as many have pointed out, similar to engineering, but still so much dependent on existing engineering approaches (*top-down*) that the reference is often made to the different sub-fields of engineering when it comes to describing the work on nanotechnological applications.

*'Tool-Box' NST*

Many of my interview partners are certain that NST is a multi- or interdisciplinary field – an analytical distinction of these two concepts is not necessarily made. However, some researchers use the latter term to emphasise the new opportunities *through* research at the nanoscale. The interdisciplinary quality of research in that area has been remarked upon as being different to other *cross*disciplinary collaborations. This different quality might originate from the involvement of biology with physics or engineering, with the more entwined physical and chemical aspects of research, and the quantum effects that render research at the nanoscale both exciting and difficult. Having said that, a small number of researchers, with a majority among the interviewed clinical scientists, feel that research on nanoscale material, especially surfaces, devices and membranes, is far from exhilarating or complicated. Nanotechnology here is very strongly perceived as just a 'tool-box' and the transfer of functionality from one level to the other without changing the underlying mechanisms. The different quality of disciplinarity here is seen as part of changing science in general. NST is 'downplayed' as a feature of contemporary science and research in general, contrasting the disruptive nature contemplated by lobbying researchers.

Another reason for the perceived different quality of interdisciplinarity in NST is connected to the focus on 'nano' and the changed physical world at that level. Research in the field seems to make researchers more aware of the different aspects of their research, more aware of the *practice* and *strategy* dimensions of their identity.

> **Researcher20**: “I think there's always been that overlap [between disciplines], it's just maybe the label nanoscience has made people more receptive to those overlaps rather than cocooning themselves in a particular discipline area.”

*Embedding NST*

Researchers see NST as another aspect, or dimension, of existing disciplines as well as a vehicle for the construction of research understanding in the social system that is academia and science in general. Only one respondent believes that nanotechnology is a discipline in its own right already (Researcher14), whilst a small number of scientists believe that NST is in the process of becoming, or has the potential to be, a discipline. Those few have affiliated with the field of NST far more than others, but have at the same time not 'abandoned' their disciplinary background. The general view, however, is that nanotechnology and nanoscience remain a means and not an end, that is an institution. However, the potential for a transition exists.

> **Researcher26**: “I think [nanotechnology is] a way of describing elements of what people do. You know, it could be a useful way for how people think about the processes that underlie the things that they are doing. I don't think it will be a new discipline.”

This quite common attitude is undermined by instances of researchers helping to institutionalise, to further construct the field of NST. They do so by imitating or following scripts in their every-day scientific work; (1) writing funding-proposals or papers that include the aspect of nano; (2) consuming journals that have been set up with a focus on nanoscale research; (3) attending conferences that have sessions on nano or are entirely devoted to it; and (4) participating in NST-related networks. Therefore, the influences of both scientific and economico-political factors in science and research practice through NST are, despite scientists' distancing, rather strong.

## 9 Summary

In this chapter I have argued that research identity is constituted by three dimensions of identification: (1) *belonging*, (2) *practice*, and (3) *strategy*. Scientist have to negotiate between being as open as necessary for disciplinary positioning and potential research areas and being as precise as possible in current research and research presentation on diverse platforms. That is, scientists need to belong to a wider group but stand out at the same time. In my fieldwork and analysis I was surprised by the remaining strong disciplinary affiliation in contemporary research practice.

My data suggest that the negotiation of research identity is influenced by markers such as interests and expertise, requirements and scripts, and external sources. The adherence to these markers seems rational and utilitarian even though the content of these markers is not necessarily of a rational nature. Personal expertise might be misjudged by researchers themselves or by governance bodies who might decline economic capital for projects because applying researchers might not have a codified track record in the area in question. In regard to NST, my respondents' accounts imply a utilitarian approach regarding funding and exploitation of both the political and scientific advantages that a focus on 'nano' can bring. However, at the same time, the structural belonging dimension of researchers' identities is more or less defended against potential influences – with scientists holding on to their respective disciplinary backgrounds – which seem to have seeped into their respective methodologies and approaches to the material world. Although many of my respondents go to length to distinguish between what they perceive as the scientifically feasible and the politically generated 'unrealistic' in NST, their boundary work accepts research aspects of NST as another element of their practice dimension and as a potential, thus strategy-orientated, element of research career management.

The negotiation of NST in research identity and thus in research practice reflects two social mechanisms. The political and the economic dimensions of research and its governance play significant roles in researchers' lives. They are enacted in different ways, as provided by scripts within the sphere of research and in relation between the spheres of research and governance, and the public sectors. Thus, two dimensions of research identity are far more fluid than the third. The *practice* and *strategy* dimensions are in constant flux, whereas the *belonging* dimension is more stable but also in a state of change in the wake of re-considerations of academic research in a knowledge society. This also impacts on presentation and negotiation of research, which take place on interactive platforms of exchange. It may not come as a surprise that NST is often portrayed as something enabling and worthwhile to pursue in research, as long as the distinction is made that here factual NST-research – in contrast to science fictional NST – is conducted. Also, there appears to be a need to emphasise that the researcher is not simply band-wagoning a flavour of the moment. Platforms of exchange provide very specialised fora for specific scientific enquiries but also spaces for crossdisciplinary exchanges and scoping of expertise-combinations, thus even providing potential starting points for discipline- or area-hoppers.

In the next chapter I take a closer look at collaboration as an important aspect of research practice in the context of increasingly complex and application/problem-oriented research. Elements of identity negotiation feature again there.

# Chapter 5: Beyond the 'Atomised Genius'

## Disciplinarity in NST Collaboration



### 1 Introduction

Unlike the Faustian understanding of science as solitary labour conducted by an estranged genius, contemporary knowledge and technology production needs to be understood in terms of a collaborative endeavor (cf. Jacob, 2001). Too complex are the problems, too particular the specific expertises (specialisations) of researchers, to undertake meaningful research in the context of application without pooling their different competencies (cf. Esparza and Yamada, 2007). This collaborative element is seen as vital for research in NST (Arnall, 2003; Pilarski *et al*, 2004; Wood *et al*, 2003). Of course, it can be argued that research ideas are still in many cases developed by individuals. Indeed, many aspects of research (searching for and reading literature, writing papers or parts thereof, supervision of young researchers and so forth) remain primarily solitary tasks, pursued in the office or on the lab-bench set apart from colleagues. This can even be more the case for very abstract or purely theoretical scientific work. However, these tasks are mainly brought to fruition within the collaborative endeavour of addressing issues and producing knowledge. Particularly for the development of technologies to be applied in the real world collaboration is required.

In this chapter I follow on from the individual construction of research identity and broaden its outlook by exploring how researchers negotiate their disciplinary identity in the context of collaborative research in NST. The aims are to examine (section 2) how collaboration is perceived by researchers, in particular how collaborative projects develop in the outset, and how partners are found and what role strategy seems to play in the emergence of collaborations. I then focus on the motivations behind collaboration by asking (section 3) why researchers participate in collaborative projects, which internal and external drivers contribute to the rationales of collaboration. Taking a closer look at the disciplinary nature of collaboration, I then turn to (section 4) the disciplinarity of research projects in NST. The aim here is to examine the consequences of collaboration. How do epistemological differences feature in researchers' accounts of collaboration? What are the differences and problems felt by researchers? What attempts are considered to deal with these issues? How is crossdisciplinary research seen to impact on individual outlooks on research? And thus, what are the implications for identity construction in the context of collaboration? In addition, I explore (section 5) how researchers communicate and contribute to projects. These are aspects of research that are of a distinct social nature and thus not necessarily referred to by researchers (as discussed in chapter 4).

Many of these aspects could have been followed up also by scrutinising a single project, thus focusing the case study even further. However, this approach would narrow the understanding of the range of different kinds of collaboration enacted in NST. It might also provide an overly positive or similarly negative view on collaboration, depending on the chosen example.

## 2 The Emergence of Collaboration

Organisation, finding partners and the perception of the role of strategy in collaboration

Collaboration takes place in many different forms and on very diverse levels, from its weakest form of informal and irregular exchanges with colleagues outside of project work to co-producing knowledge, and to learning from partners within an integrated project. Here, I explore how collaboration between research partners is described and experienced by scientists. In chapter 7 I suggest a model of the diverse levels of collaboration.

Collaborative projects have been described by many of my respondents as emerging from a number of existing relationships as well as being the result of *ad hoc* decisions. Often, these decisions follow structural requirements, such as a complex problem or funding policies. The 'organisational' starting points might be seminars or workshops offered by research institutions, where researchers with common or overlapping interests can exchange their ideas.

> **Researcher7:** "[We are] members of [an NST network that] is cross-Uni [...]. Anyone who is interested in nanotechnology, so people in Medical School, [...] people in [Engineering], people in Chemistry, can be members of that. And it's an idea so that every now and then they have seminars and events and things that we can then get together and collaborate with biologists or geneticists, or whoever it'd be."

*Collaboration from Networks*

The same can be said about conferences, which provide fora for both exploring research in the field as well as presenting own research. Researchers might be approached by colleagues who are in the process of setting up or have already set up a project, and be invited to contribute their specialised expertise, or vice versa. Networks, generally, are seen by my respondents as being helpful to meet potential project partners. They do so to further ongoing research, but also, interestingly, to define a certain problem area to investigate.

> **Researcher19**: “It's just networking, really. And sort of word-to-mouth mainly. You can go to conferences and that, [...] see one or two sort of good ideas of areas to explore.”

Often, networks such as dedicated research organisations or conferences focus on certain topics in an attempt to proliferate research in a certain area or field. For NST, a considerable number of such networks have emerged (as discussed in chapters 2 and 4), regionally and on a national level in the UK with research links and institutions within and between universities. Also on the international level, for example within the European Union, many discussion fora and research collaborations have been established, both for scientific and non-scientific aspects of NST. These networks are fostered by science policy (especially in view of competing with other heavy research output regions of the world) and by an apparent drive of researchers to both make use of science policy (for example by re-labelling ongoing research) and to develop nanotechnological research. These networks have been referred to by my respondents as helpful in many ways: to get to know new aspects of research; to meet potential partners; and to provide funding.

*Collaboration in/from Supervision*

Collaborations might also arise out of supervising postgraduate or post-doctoral projects. Since, in many cases, supervisors provide the framework and general thrust of the project in the natural and physical sciences, their research interests can directly benefit from this kind of collaborative research. Results here can provide the scientific or technological basis for follow-up projects. The position and influence of supervisors is probably best symbolised in their name being on every poster, presentation or publication the supervisee will produce during their 'master-apprentice'-like relationship. The supervising scientists seem to be very aware of the controlling influence their research interests have on the research of their students. In turn, it might be seen as necessary to help students acquire skills and knowledge to become part of the social structure of the particular disciplinary structure, or science in general (cf. Bourdieu, 1987).

> **Researcher9**: “Well, often these collaborations will involve probably a person. It might be a PhD student or a postdoctoral research associate actually doing the wet laboratory work.”

> **Researcher25**: “So, there's two students at the moment that I have, PhD students [...]. It's usually the supervisor's project, not like in Arts where the student more defines the project. Yeah. So I have to find a project for them.”

*Research Basis for Collaborations*

Very similar to this kind of starting point for collaborations, and apparently very much in line with the regime of science, is the development of projects out of previous research. Indeed, this evolution of research projects seems part of the rationale of doing research, according to my respondents' accounts. This rationale is constituted by (1) external requirements to produce knowledge and technology, (2) individual specialisation and aspiration to progress personal research, and (3) external requirements of building up a more or less linear track record of research in a specific area that can provide expertise for continued research.

> **Researcher19**: “[I]t proved it worked [...] in the lab and that. So, the next stage: it's now a European grant. And we try to sort of develop it, and the European partners are trying to sort of put it into a proper package and that. So, I mean, that one is going forward [from lab to application].”

> **Researcher25:** “So, we had developed a way of pattern, or patterning [...] that we had learned in another collaboration [...] and then, you know, it was a couple of years later then: 'Oh, we can use this [for something different].' So, I knew how to make the surfaces and asked him: would he be able to run the spectroscopy on these surfaces that we'd made. [...]”

The results of one research project might lead to consecutive collaborative projects, not necessarily one right after the other, but still linked to one another either via the general interest area of the researcher or in response to external influences. One aspect might instigate another project, perhaps because research questions have not been answered in depth, or owing to new questions.

> **Researcher26**: “There is a common goal in those kind of projects that I am doing. The common goal is to understand how cells relate to a surface when they're growing on it [...]. So, that's my aims, so that's how I'm exploiting [my collaborators'] technology [...].”

Generally, two main starting points for collaborative projects have featured in the accounts of my respondents: being made aware of research areas or developing own ideas through networking; and taking aspects from previous research into follow-up projects. Thus, the awareness of potential for collaboration seems to draw quite regularly from other (low-level) collaborative activities such as networking or previous research with students or colleagues.

*Initiating Collaboration: Funding*

In order to develop and/or establish collaborations, my interview partners repeatedly describe funding as one of its major factors. Indeed, funding features throughout their accounts of initialising or joining projects. Grants, for example provided by networks, appear to render setting-up projects and getting other researchers to join much easier. At the same time, funding can come with requirements regarding the focus of a project (problem, area or field); elements of the approach, for example interdisciplinarity or internationality; or to what ends research is conducted, for example for industrial or commercial applications.

> **Researcher7**: “Part of my funding, it comes from [an NST network at the University] because I do a lot of international collaboration work, partly with [a European nanotechnology network], as also with people [outside of Europe].”

> **Researcher19**: “What was really useful was [the] grant from the MRC to get engineers and medical people talking to each other. And there's quite a few projects spun-off of that.”

Researchers might have to trade some of their research liberty in exchange for acquiring funding to fit in with funding streams and science policy, but it also allows them to explore new areas and different aspects of their own research activities.

> **Researcher15**: “One of the noticeable things within the last five or six years was that we were heavily relying upon [European] funding, and [...] how that was structured drove [our research activities].”

Many grants support the set up of projects to conduct research right away. However, other funding might be more of a scoping nature, allowing to explore an area of research with the aim of fostering projects and intensive research in that area or field. This has been prevalent in the early days of NST funding, as some respondents describe in their affiliation towards NST in chapter 4. Funding here becomes a policy instrument but, again, also presents an occasion to explore new or further aspects of one's own research specialisation.

> **Anonymised Researcher D**: "So that's what the whole purpose of the [grant] was. For three years I, as one example, have been going around, talking to all the different groups, trying to orientate them in terms of what medicine wants, and the other way around, what physics can offer or whatever it is. And try and educate and bring people together. [...] So, it's been a slow process of - it's not exactly education – but certainly making people more aware, raising awareness. And then beginning to identify people who are interested, and then beginning to provide the method and means of interacting. So, this would not happen by chance, I don't think... it's difficult by chance."

Here, first interests are explored and then a basis formed in accordance with the outset of the grant. The aim is described as encouraging research in a certain area, and bringing together researchers who otherwise might not have considered to collaborate. But again, the exploitation of available funds might also be difficult due to different allocation policies implemented for different grants. Whereas several of my respondents agreed that they have been able to benefit from funding from initiatives or networks, one researcher remarked upon the sometimes arbitrary nature of allocation processes, which in some cases seemed to stand in contrast to the aim of initiatives to set up networks and sustainable, on-going research activity.

> **Researcher20**: "I would have thought that a proper part of a university innovation centre would be bringing researchers in. Instead it seems to have just funded a few specific projects like any other set of research grants. It didn't seem to be specifically making a centre. [...] To be frank, I'm a bit disappointed by that. I thought... Because what it's done, I think those projects have now ended and I don't see... They might have generated a few symbol collaborations [...] but it doesn't seem to have produced anything sustainable in the long term."

*Initialising Collaboration: Ideas and Aims*

Apart from acquiring funding, my interview partners have mentioned other critical tasks and challenges in getting started with collaborative projects in NST. It can potentially be a rather long process of negotiating aspects of a project before potential partners actually agree on collaborating. Some of these challenges are to decide on the scientific and/or technological problems of the project, and which approaches to take to address these problems. Also, personal agendas need to be discussed and negotiated.

> **Researcher7**: "[G]eneral difficulty is probably what people see as being the more important priority of the project: where do you want to concentrate getting effort, to get results, you know. Or the thoroughness of the project is another area, I suppose. [...] Those are the areas where it's difficult, not the actual science itself, but the approach to a project."

> **Researcher11**: "[T]hen you have to go through this sort of exploratory relationship to try and understand what you can offer them, why have they contacted you, and what they can offer to you in return."

> **Researcher26**: "I think it's relatively easy in terms of we kind of let the science do the talking. [...] A group will have a poster on the walls, saying we made these surfaces, you know. And the bottom line could be they could be useful for x, y and z. And you either go along and say 'why do x?' or 'have you thought about doing p?' [...]."

It might not be as easy as Researcher26 puts it in "let[ting] the science do the talking". It stands to reason that it can be a rather difficult process of finding a consensus or general agreement on what direction to pursue. Difficulties can also originate in the different disciplinary backgrounds of researchers and their individual rationales for engaging in this project. One of my respondents pointed out very clearly in what can be seen as a summary of the above quotations how complex setting up a collaborative project can be.

> **Researcher27**: "At the beginning of the project we hired sixteen new people coming from a mix of these different backgrounds and getting them to understand the research questions that lay behind getting the grant, then understanding each other's agendas, and then kind of managing a process of interaction and working, and, you know, sort of

> overcoming skepticism, sort of developing a kind of appreciation of the skills that other people had."

Indeed, the process of finding the 'right' or 'appropriate' partner is rather a crucial one in the process of setting up a project. Thus, it is one of the most important tasks and cannot always be successful. Finding the potential partner who can provide the project with expertise, equipment, services and so forth that will fit in with the thrust and problem, or aim, of the project as well as spark interest and inclination in the other researcher(s) to participate is a complex process that can be supported by some measures. Many of my respondents have mentioned that they are collaborating on NST with colleagues they know from dedicated networks; through shared research interests or the progress of their research; and by being approached from the outside, that is from people they have not met or collaborated with before.

In summary, collaborations often arise out of previous collaborations, and are either based on or draw from researchers' interests and existing research. At the same time, various platforms of exchange (chapter 4), such as networks, seem to play a crucial role in setting up collaborations in the field of NST. If successfully implemented, they support getting to know scientists with shared interests through the overarching agenda or problem of a platform. It acts as an intermediary, but also as a gatekeeper since requirements may exist for being able to participate on that platform.

*Initialising Crossdisciplinary Collaboration*

This begs the question as to how researchers actually approach potential partners from disciplines other than their own. Especially in the case of new and emergent research fields, such as NST, an institutional push towards collaborating with disciplinary expertise that might not necessarily have been considered possible or fruitful before, can be helpful. Many of my respondents feel that networks have made it easier to approach colleagues in diverse disciplinary areas.

> **Researcher12**: "[T]he initial idea [...] to set up [a University-wide nanotechnology network] and bring people together from across different disciplines was an excellent one, and it has helped my research enormously because I was exposed to those engineers

> [...] our relationship and our collaboration has gone forward, you know, hugely, since that time. [...] Collectively we've done a hell of a lot better than we would have done individually. And it was because of that initial idea to set this up and put people together that we are still working together. And that's been very successful.”

Local networks can be a good starting point for research within an area less familiar, or even new to the scientist. Collaborations emerging there might then lead to the involvement of research groups with national or international links, often with varying degrees of success.

> **Researcher15**: “[W]e would interact [...] within fora within the School or the University. There might be research management group meetings or research seminars. Then, the next level from that is regional, national, international conferences and symposia.”

I mentioned platforms of exchange before. For the actual setting-up of projects, dedicated research networks are probably more helpful than conferences, which are more frequented for the exchange of ideas or discussion of problems and issues within separate research projects, problems that are usually not mentioned in papers published in journals.

Emergence and persistence of dedicated networks and conferences rely on the premise of shared interests, or common interests. The formation of such platforms as another level of collaboration can draw on existing instances of collaboration, such as projects, networks or other kinds of more personal relationships, with the intention of focusing research or complementing activities.

> **Anonymised Researcher E**: “We put ourselves together, and so then become the Chemical Nanoscience Centre. But we're still waiting to get formal recognition by the University, as a centre. [W]e're also [...] members of [an NST] cross-campus [network].”

However, collaborations do not only arise out of dedicated networks, but also from more personal relationships such as previous research projects, taking research further with collaborators who seem to have worked well together, or from supervising students.

> **Researcher11**: "[O]ne thing is that you tend to work with people that you worked with before. And that's not unnatural because I think you demonstrated that you can collaborate and so on."

Another approach is to include previous service providers in the actual research because they might have demonstrated that their expertise could be helpful in further research, or due to their increased interest in the project.

> **Researcher7**: "They would [have] nothing to do with the project apart from providing that surface to you, or then, from that, if it worked well, become partners in collaboration."

> **Researcher21**: "I get silicone waivers from them for my research. [...] We just set up a brief conversation like this [...] and we discussed their problem and made some suggestions. And we started [our project] from there."

Research partners might also be found outside the actual sphere of research. One of my respondents told me that she had met one subsequently oft-times collaborator through playing basketball with him. She did not elaborate, but the chances of such encounters appear rare, and I suspect that their meeting might have come about within the academic environment, for example in recreational activities of lab-staff or from sports organised among staff of the school or institute.

The third principal approach to finding potential collaborators is either approaching or being approached from the outside, that is by aspiring contact from readings, presentations, or through recommendations of colleagues. Being approached by someone from the outside could be perceived as a sign of acknowledgement of research performance, but it could also mean that interest in collaboration is not necessarily mutual.

> **Researcher11**: "Often people become aware of what you have done through publications. And they contact you accordingly."

> **Researcher12**: "It would depend on the goals of the projects. I would consider it but it would really depend on the goals of the project, and what I thought we could contribute

to. I wouldn't just do it because somebody asked me.”

**Researcher16**: “We went off to a conference last year where we presented some work we'd done, by our undergrad students at the time. And [the project initiator] was really impressed with it and invited us to join their, to join the party, really.”

**Researcher21**: “There is a researcher in Liverpool, who is working in biochemistry, she has an interest in magnetic resonance imaging. So, my first port of call would be to go to this person. I met her at a conference.”

Collaborations develop best when initiated through shared research interests, which can include the networking variant of finding partners and the continuation of working with partners where experience has shown that collaboration can work well. The role of personality in collaborations adds a further dimension to this postulation. I elaborate on this element in section 5 of this chapter.

*Strategies of Initialising Collaboration*

Networks and conferences support the development of collaboration. However, a strong theme in researchers' accounts is the *ad hoc* basis from which collaborations develop. This implies that an overall collaboration strategy is missing.

**Researcher20**: “My experience in general, not just here, is that collaboration seems to be [a] very accidental process.”

**Researcher25**: “Normally it's if you just meet the right person who shares scientific interest as you and you can see there is something you can do together. So, usually it is fairly accidental.”

I believe that this perception, however, is a sign that engaging with colleagues in research is marked by routine, and that the accidental nature indeed stands for an economic approach to collaboration. A potential partner is sought when required, which in itself is already part of a strategy, comparable to the 'just in time' production and storage strategy in industry to save resources and storage space as well as to avoid over-production. At the same time, external resources are turned into tactical instruments. Networks are utilised, funding is exploited, policy interest in new areas is addressed in research labelling or understanding, and research is conducted with colleagues from previous projects. In fact, the complete absence of strategic elements would make it far more difficult for a researcher to conduct research. Simultaneously, the planning aspect of research projects is of great significance to funders and to scientists, especially to managerial scientists.

> **Researcher27**: "So, I've invested a lot of planning in how we structure this, and really, sort of trying to force people's interactions to generate the synergy."

At the structural level, researchers' responses imply that while the existence of networks are seen as very helpful, a more controlled or bureaucratic regime would stand in the way of research for individual researchers. Researchers would appreciate a more formal system of helping to establish collaboration but would not welcome a very directing structure that would impact on their choices of potential partners and potential problems/aims. Both are already influenced in regard to required expertise and to certain funding programmes.

> **Researcher7**: "There is enough bureaucracy in trying to get money out of the government. [For setting up collaborations] there's no, sort of, formal arrangement at all. And I think that's the way people expect it. You know, you take the initiative yourself and just go and try. There is no, sort of, aid to help you collaborate or work with other people. Apart from maybe [a network at the University], which then just let's you know what's going on. It doesn't actually give any system of collaboration, but it [...] raises your awareness that actually in your own university there are these people doing these things, as well."

> **Researcher20**: "It's important that it isn't enforced because I don't think that works at all. There has to be a common interest. I think it'd benefit if there were more formal fora or areas in which discussion could take place, just, you know, to incubate, to start these things off, to get people discussing their ideas and being willing to, you know, to be open to the idea of collaborating."

A slightly more formal organisation of setting up collaborative projects, as well as for the management of research, seems welcome. Some of the scientists with a managerial role in research mention the difficulty of organising funding across faculties and schools where cost centres are based at an intermediate level of organisation. The access to funding emerges as a critical issue in setting up collaborations, especially across institutional and possibly across disciplinary boundaries within academia.

In this section I have identified elements coming into effect in the emergence of collaboration in NST. My data suggest that collaboration here rests on existing research as well as on the institutional fostering of research in this area. A personal dimension in communication also seems to play a role, which I follow up on in section 5. Main contributors to setting up research collaboration across disciplinary and institutional boundaries in NST are diverse platforms of (open) exchange (see chapter 4, *Disciplinarity in Sources of Research-Information*), such as dedicated networks and conferences. Nevertheless, researchers perceive an accidental nature in setting up collaborations. This perception illustrates the need to react quickly to available funding and to look for potential partners at a time when research ideas have emerged and contributing research is available. The strategic component that appears missing, then, refers to the institutional (structural) dimension of science. However, in light of researchers' accounts discussed here, it is viable to say that researchers have indeed developed a strategy in setting up or joining collaborations. This becomes strongly visible in reflections on the benefit of platforms of exchange.

## 3 The Rationale behind Collaborating

Necessity and personal motivation to collaborate

Funding, as it features in the accounts of researchers in the previous section, displays a significant influence on how research is conducted. It is seen as a powerful pulling factor to initiate or join collaborative endeavours, bringing out what I called the *bourgeois* element in a scientist's identity in chapter 4. The access to grants is closely linked to the content of research, and often to the applicability of research outside academia. In this section I look at what I referred to before as the external requirements of scientific research, which are conceived by my interview partners in regard to motivational aspects for collaboration. Subsequently, I explore the more personal, internalised scripts of conducting research.

Two kinds of external requirements feature in scientists' accounts and the debates around NST: the *societal dimension* of requests or demands from outside academia; and the *dimension of the science regime* in general, to which researchers have to submit.

*Societal Rationale*

The societal dimension might be seen as lending a rationale for certain aims or problems to be solved in research. It can then be understood as a form of research legitimation. Requirements are perceived to be coming from outside the sphere of research, and science is seen as contributing to solving societal problems. Thus, nanoscale research is often described as problem-driven towards engineering or medical applications in the real world. Scientists who themselves are more interested in basic research tend to collaborate in projects that address such problems, and they present their expertise in NST as being complementary in solving a real world problem.

> **Researcher7** (chemist): “In electronics itself, there is funding, and it's application-driven because people demand: it seems they always want the bigger, better, faster, you know, fancier things. [...] And to keep up with [the] reduction in size of components and the density of transistors on a chip, you know, they're going to have to think of a whole new approach to design their computers [...].”

> **Researcher21** (physicist): “I do a little bit of nanotechnology research with some engineers here [...]. They have specific problems, problems of the real world. They want to make electrical contact, for example, with very small structures. So, what we're trying to do is use some of the nanotechnology techniques of electron beam lithography to create deliberate structures that will allow [...] us to make electrical contact [...]. So, it's very, very tedious, really, and not so interesting, but technically very difficult to do, and it will be very useful when it's done. “

As personal interests might not lie in the field of application or a particular research area, the focus on applications presents strongly the case of the transgression of institutional boundaries between science and other professional domains (cf. Nowotny, 2003) in influencing research trajectories. This, however, is not a one-way road. The societal dimension is complemented by the technological state-of-the-art allowing to conduct certain research, or even to comprehend a problem in a certain way.

> **Researcher2**: “So [my project partner] came up with certain ideas about this hydro-gel that would facilitate the replacement of the hip joint. And, obviously, this idea occurred to him due to his involvement in nanotechnology and all that stuff.”

The merging of science and technological application in academia appears to be very strong in the case of the clinical sciences. The clinical scientists among my respondents have expressed the need to address societal problems in their research, making this field a good example for technoscientific research.

> **Researcher11**: “I certainly tend to respond much more to external stimuli, rather than to set the goals myself. [...] it's very much an applied issue in that [...] we're looking to solve a problem.”

> **Researcher17**: “[My projects] are mainly orientated towards specific health-care problems.”

That application-driven dimension is also very strong in NST application. Many NST-research activities are geared towards development in nanobiotechnology and applications for nanomedicine.

> **Researcher12**: “We are driven by what the clinicians require, what they desire, what they think that they need to have. So, if they say [it would] be very good if they could measure a particular species, then we develop a technology to allow them to do that.”

*Technoscientific Rationale*

The technoscientific nature of NST is reflected in references to industrial research as being another external driver towards collaboration in the field, but also beyond. Not only should academia provide ideas for research in the real world, as industrial research is bound to do, but a feeling of competition emerges in scientists' accounts when they reflect on industry's utilitarian approach to research. Collaboration suddenly becomes a necessity to keep up with the perceived competition.

> **Researcher7**: “[C]hip-making companies [...] got teams that do basic research, and they collaborate with universities, maybe [...] trying to collaborate with us hopefully [...].”

> **Researcher14**: "And, you know, if you're gonna be credible on your working on a technology area, like microelectronics, you're competing with the large companies, the 'Intels' of this world. They have a group of people with different backgrounds working together, so if you're gonna compete you have to be the same sort of group. If you can't, then you're gonna do your own little thing, and that might be good stuff, but you're not gonna be able to be, sort of, recognised as being a major contributor to the area."

The reference to industry's drive to rely on crossdisciplinary research teams can also be understood as part of the structural requirements in contemporary research. Collaboration of diverse expertises can address complexer problems and even provide access to existing, but previously unreachable, and new problem areas. NST is perceived as just such a field, encompassing many different areas of expertise, but also allowing new perspectives for the conduct of research. Therefore, to render research in this field meaningful and successful, researchers with different scientific backgrounds are required to work together.

> **Researcher19**: "It's such a multidisciplinary [field that] probably no one person can do it effectively, you kind of have to be in a group. [W]ith the biosensor kind of stuff, it's sort of great to do that, but when it comes to biochemistry I haven't got a clue. So you kind of need the experts in that field."

> **Researcher25**: "[W]e wouldn't be able to do that by ourselves. So, if we need to do lithography, for example, even the simplest things, we wouldn't be able to do that here, we would have to find someone else to do the lithography [...]. And if we were interested in things like transistors, you need a physicist, or an electronic engineer [...]. Even if you know quite a lot of physics, it's too far away to do it yourself. So, that's where you do need collaboration."

These quotations might imply that collaboration is seen as a necessary evil, and in some instances this perception might be supported. However, when considering situations of personal interests being complemented and furthered by contributions from partners with different backgrounds, the advantageous nature of collaboration is emphasised. For some, the cross- or multidisciplinary nature of contemporary research even holds advantages beyond the individual scientist's interests, but can further research interests in the overall context of scientific endeavour.

> **Researcher15**: “And it's the opportunities and the challenges that are falling down the cracks between disciplines. That's where the opportunities exist now. [...] It's not just between one or two disciplines, you know, it's between many disciplines, you know. It's almost a multidimensional map.”

The need and utility to conduct research between traditional disciplines implies broadening epistemological approaches on a theoretical level. With practical considerations in mind, others draw out the very methodological nature of collaboration both in being more effective and creating better research as well as providing opportunities to being better informed and, through collaborators, having complementary knowledge and skills available to contribute to the project at hand.

> **Researcher9**: “I think that chemical expertise, physical expertise and engineering expertise and materials expertise, mathematical expertise are all very valuable skills and could be used to good effects in understanding biological problems.”

> **Researcher12**: “Well, you see progress much quicker, because you're using all of the other people's skills complementary to your own to drive forward the overall project in a much more efficient fashion.”

> **Researcher22**: “I think collaboration is very important [for nanotechnology] because there is now so much information tied up in that technology, it's almost impossible to keep up [for] an individual group [...] so they actually need to collaborate.”

All of these opinions refer to crossdisciplinary collaboration as paving the ground for additional ways of understanding the world, for creating synergies and pushing the boundaries of knowledge. This can happen for basic and for applied science in academia that also reaches out into society via the development of technologies.

> **Researcher14**: “I can offer things to them that they can't offer, and they can offer things to me that I can't offer. And together we can do something, which is much better than that.”

> **Researcher20**: “So, the chemistry partner and I have a sort of fundamental science outlook and then we might not see problems that would prevent a science becoming a technology, so that's where the engineers come in. So, each bring in a different perspective, a different viewpoint and different expertise.”

Advantages in collaboration also regard different specialisations within a shared disciplinary background. New ideas and insights might emerge from collaboration, both in individual disciplines as well as for wider areas or fields of enquiry. The drive to learn is not an insignificant one, especially since research is ongoing, and collaborative projects of a larger scale are usually not embedded within the particular interest fields of the contributors.

*Practical Rationale*

Apart from purely scientific expertise, collaboration might emerge due to aspiring access to certain equipment and to partners who have the skills to work with it. Equipment might be very expensive or still in experimental state, so that the facilities hosting these instruments might also be hosting research groups from other research institutions on a regular basis.

> **Researcher15**: “No university can have all that range [of equipment]. And they certainly can't have the differentiating thing, which is an expert to run the thing. So, it's very much accessing different pieces or different arrays through other people's equipment.”

> **Researcher18**: “We take measurements there [...] because there is [a] facility that we don't have at the University or anywhere else. Maybe it's [the only] one in the country, so you go there. [...] And sometimes you get help from people, which run such a big facility.”

> **Researcher25**: “There was one group [...] we did work with a little bit [...] just analysing the products that came out. Simply because we didn't have the equipment.”

Short-term collaboration might evolve into a more frequent partnership, especially if the techniques and skills necessary to use the equipment and to interpret the data from these are rare. Then, collaboration might also culminate in co-written papers and project applications. On the other hand, visiting researchers can acquire skills from their short-term partners and apply these later on again.

In the context of structural requirements of science, collaboration might be required to render the investment of funders more sustainable by producing research outcomes utilisable in follow-up projects. This might be part of science policy to spawn further projects through the funding of an initial one. Developing a new technology can be another potential aim, where numerous research backgrounds are already insinuated by the setting of the project aim. Here, managerial expertise will be required to set up and administer such a potentially large and long project.

> **Researcher19**: "[For] the big European [project], because you're making a whole instrument, you need sort of electronics people, fluidics people, instrument people [...], just a whole range of backgrounds, management type of staff."

> **Researcher25**: "They like to have a lot of collaborators on grants like that, don't they. If you say you can do it all yourself, actually, I think they don't like it."

*Track Record Rationale*

Another important rationale for research is to produce and publish research papers. At the same time, the academic research track record (a structural requirement of the science regime) is enhanced by research experience and publications. Since research relies on increasingly expensive instruments and tools and is perceived as being required to take existing research further, as is the case in NST, collaboration (also across disciplines) becomes a necessity.

> **Researcher7**: "[Potential collaborators want to know] what's in it for them really as well, you know. If there's potential for papers or funding for them."

> **Researcher19**: "Whatever you do, you kind of want a paper out of it."

> **Researcher21**: "The motivation for me, the motivation for modern research is quite complicated. Because we get judged on the amount of... the quality of our research papers but also on the amount of funding that we bring in."

In addition to these societal and science-structural rationales for collaboration researchers also refer to what can be seen as being internal drivers or internalised scripts. These are more personal reasons for why collaboration in research might be aspired, closely connected to research interests. The most personal reason hereby is probably simply preferring to work with people as it renders the process of research a social or community experience. Or because a certain research aspect or task in the project might be undesirable, as one of my respondents pointed out.

*Research Interests in Collaboration*

Research interests are an important personal driver. Scientists want to be able to actively contribute, and be fully included in the actual research process, unlike service providers or technicians. Thus, researchers will often only join a project if they are interested in its problem or aims; if they can try out new areas or approaches; or if they see a relevance for their research.

> **Researcher18**: "I always like to take an idea, which excites me. If it's boring I just don't want to go there, it's pointless for me. Maybe would be good for someone, but... You know why? Because your life is short [...]."

> **Researcher21**: "I just was interested, it was something that caught my attention, my imagination, I like the idea of doing new things."

> **Researcher26**: "There is a common goal in those kind of projects that I am doing. [...] So, that's how I'm exploiting their technology if you like."

To pursue own interests would probably be best served by initiating projects. On a larger scale, for example in a relatively new area of research, this might prove to be very complicated. In the case of nanomedicine, one of my interview partners was able to initiate a scoping grant to explore the possibilities of conducting research in this area at his university. This enabled him to pursue his interests in a relatively new area by getting to know potential partners and their potential contributions as well as furthering the cause of his research interests.

But even on a smaller scale, it will not always be possible to start a project, and not always can researchers divide their attention in equal parts on several projects. Then, following research interest seems to be a rather deciding factor in the decision-making process of whether to join a collaborative project or not. However, should the problem of the project not be embedded within the exact interest field of a potential contributor – as would be the case with most larger projects that aim for the transfer of fundamental science to technology and further to an application – researchers can still be swayed to participate. Secondary resources such as time and utility play a role here. Scientists might then approach the collaboration with a more utilitarian outlook to learn of different methods, which could prove useful for their overall research interests.

> **Researcher19**: "Anything that I'm interested in [...]. And you have to be able to bring something to a project [...]."

> **Researcher21**: "So, my genuine interest would be, is only really to collaborate with people where there is some genuine intellectual input [...]."

This might be connected to the apprehension towards being a supporting partner, by not being fully included in the research and its outcomes, but spending time and other resources on a project that is not at the forefront of personal interest and development. This is then likely to affect the track record and research esteem in negative terms. The Research Assessment Exercise (RAE), conducted at UK universities since 1986, is one element of the academic science regime providing researchers with a very strong notion to focus on a smaller number of significant and prestigious research projects and publications instead of contributing to a wider scope of research.

In this section I have identified a range of reasons for why researchers participate in collaborative projects, especially in crossdisciplinary ones. In NST, strong influences originate from external factors rendering research interesting (and worthwhile) to spend time and resources on. Researchers thus have to consider and manage their very own preferences and interests both of a scientific and strategic kind, and bring these to bear in negotiation with external requirements that come from outside the sphere of research, and are inherent to the structure of the science regime itself. On a different level again, the disciplinary and epistemological differences between collaborators have to be navigated as well, which I examine in the next section.

## 4 The Role of Disciplinarity and Epistemology

Dealing with differences of collaboration in NST and their impacts

The field of NST is usually described as constituted by the input and approaches of different disciplines and sub-disciplines, as I have pointed out in chapters 2 and 4. To conduct research, many kinds of expertise are needed and diverse disciplinary backgrounds are involved. The majority of my respondents also describe collaboration in NST as an undertaking between different disciplines. The combination of disciplines depends on the problem focus or technology aim.

> **Researcher17**: "[Y]ou've got people who are cell-biologists, you'll have people that are perhaps protein-chemists, or chemistry. And then you have people more on the physical side, engineers or silicone manufacturers, physics [...] that's a fairly typical kind of contribution."

Despite this general premise, there are fine distinctions that can provide clues as to how researchers understand the disciplinary nature of collaboration here. Some refer to their projects as being cross-, multi- or interdisciplinary. Often, no qualitative discrimination is made in regard to the use of the prefixes, scientists tend to be less consequent in using these terms. However, some of my respondents indicate the kind of collaborations they are involved in.

*Disciplinarity of NST Collaboration*

The crossing of disciplines (crossdisciplinarity) is used by one of my respondents in a descriptive way, pointing out that several disciplines are involved in his work. The focus in his understanding of crossdisciplinary research seems to be very much on an area of interest.

> **Researcher12**: "[...] I've always [worked] across disciplines in the areas I've worked in."

Multidisciplinarity, however, seems to be rather set in relation to the *contribution* of certain partners and disciplines. When a scientist talks of different contributions to a project *per se*, then the collaboration can be more of a multidisciplinary understanding pursuing a shared general aim.

> **Researcher11**: “I think that if you take the groups together, they are multidisciplinary, and I think we all come to the table with something to offer [...].”

The interdisciplinary understanding of collaboration tends to refer to taking the aim and its addressing further by creating synergies towards a more comprehensive solution of a problem or even towards a novel approach, where collaboration of different disciplinary expertise is more than the sum of its elements.

> **Researcher14**: “[...] I can offer things to them that they can't offer, and they can offer things to me that I can't offer. And together we can do something, which is much better than that.”

> **Researcher17**: “Research in [clinical applications] has always involved researchers with different backgrounds [...] because you're dealing with a piece of metal and the human. [...] So, that's a long-standing interdisciplinary kind of research [...].”

However, for scientists the terms ascribed to social activities in their research are less of a concern than the progress of a project and its results, as two of my respondents emphasised. Nevertheless, the way scientists approach problems influences the trajectory their projects can take, whilst social agency is fundamental to the functionality of collaboration. One example lies at the very heart of collaboration. The mind-set of project partners might have an impact on how researchers view the contributions from their partners, and how they approach ideas and recommendations in relation to their own specialisation and research. A range of ways of dealing with 'new' ideas and methods have emerged. I examine these in the last part of this section. Here, I focus on how collaborators and their input are perceived.

*Perceiving Partners' Disciplinarity*

When considering their partners in NST projects, my respondents try to categorise those along disciplinary boundaries, which still provide a strong pattern of identification. Some feel that they have a clear understanding of the different disciplines involved in their projects, whilst others refer more to the specific expertise, the knowledge and skills that partners contribute to the projects. However, at times the *belonging* and the *practice* dimensions of their partners' identities become diffuse. A clear disciplinary distinction is probably the easiest for researchers who work with the same colleagues on a regular basis and who then refer to their partners' background as these would.

> **Researcher14**: “I'm working with electrical engineers, physicists, material scientists, basically. [pause] I don't think there's a chemist involved in that. If we take multi-scale modelling, I'm working with mathematicians, physicists and computer people.”

This quotation suggests confidence regarding the disciplinary backgrounds of collaborators. However, such a clear-cut distinction can also illustrate a limited awareness of other's specialisations, while the categorization according to disciplines might be simplified and not correspond with partners' self-identification. Other respondents reflect on specific tasks, knowledge or skills instead.

> **Researcher9**: “The other participant is... [laughs] a nanotechnologist, I suppose, someone with the background in making devices in silicone and physical properties of those devices.”

Data suggests that researchers are not certain about collaborators' disciplinary affiliations. This can be connected to their own complex identity negotiation, resting on the two dimensions of belonging and practice. Both can differ greatly in regard to disciplinary affiliation and actual specialisation. This uncertainty then, I propose, is based on the necessity to be as precise as possible about their own complex specialisations and contributions in research projects. At the same time, the more generalised approach to partners' specialisations and affiliations is based on the prevailing contributing nature of many or even most collaborations, a 'side-by-side' instead of a 'together'.

This links with researchers' positioning toward NST. My interview partners tend to negotiate their affiliation with nanotechnology or nanoscience through research partners or projects, rendering their link to NST indirect, and contextualised by aims or aspects of projects that can be described as 'nano'. In chapter 4, I have identified possible reasons as critical distancing.

*Personal Disciplinarity in Collaboration*

However, the wide disciplinary configuration of collaborative projects in NST shows an influence also on how researchers view themselves. Being able to translate between disciplines has been emphasised by a number of my respondents as being very helpful. At the same time, it is seen as a feature distinguishing oneself from collaborators.

> **Researcher11**: “Yeah, I'm more comfortable with them perhaps than other people might be because I can see the [...] viewpoint from both sides. Having got a background in science and engineering, I can see [...] both viewpoints. So, there is no discomfort.”

> **Researcher16**: “[T]hen there will obviously be the translation problem between chemistry and engineering, physics, but that's where my expertise can help.”

> **Researcher18** (chemist): “I think if you are a chemist, you have a better chance, really, to interface.”

This connects to the necessity that specialised expertises have to overlap, or at least connect in certain aspects. Communicating disciplinary differences makes it possible for researchers to collaborate and for the project to progress.

> **Researcher12**: “I don't understand everything of every aspect of the project, but I understand enough about some aspects to have an opinion. And there are other people who have similar knowledge to me, who have better knowledge in a different area, so I can always talk to them about how they understand it compared with how I understand it.”

Due to difficulties potentially occurring in crossdisciplinary communication, some researchers have pointed out that they prefer to work with colleagues from within their own disciplinary frameworks. There are still different specialisations but the basic elements of research expertise, such as the majority of terminology and methodological approaches, are shared.

Indeed, the epistemological issues in collaborations are considerable, although they are at times played down by some of my respondents. This might be an indicator for little engagement with collaborators and their backgrounds on one end of the spectrum, or for great familiarity in dealing across differing disciplines at the other end. Some differences can be overcome quickly or in due course, but more profound problems may emerge from differences and prolong the project considerably, or even jeopardise it altogether.

*Differences between Collaboration Partners*

The most common differences raised are of language and terminology; approaches to understanding or addressing the research problem; and methods of research. Differences in terminology can encompass the use of unknown terms, having different terms for the same thing, or having different meanings for the same term. For specialisations of a similar or close disciplinary background, differences might be slight, whereas for specialisations that are further apart epistemologically, the whole range of differences can apply.

> **Researcher23**: "One of [my project partners], he is into the area of mathematics and modelling and fluidic mechanics. I'm doing fluidic mechanics, but on the microscale or nanoscale [...]. But still it becomes quite difficult for him to understand what I'm talking [about] because he doesn't know the biological aspects [of my work] or other molecular aspects, which are happening at that scale. [...] So it becomes difficult talking to him. Whereas my [project partner] from here [with a] background in micro- and nanotechnologies, he understands it [well], but his terminology [...] is quite different [to] my other [colleague's] and myself because I've become more experienced in this and specific in this."

Differences in language, methods, and understandings of a project aim can have a significant influence on how researchers approach the aim, and how they understand potential solutions or applications. Awareness and acknowledgement of differences is vital in order to avoid miscommunication. However, translational problems can also originate in different histories of disciplines. They may even undercut the realisation of certain methods or understandings (cf. Fuller, 1997). In many cases, my respondents express the opinion that it is not the 'science' that is problematic but the approaches to it, how the scientific details are codified by the different collaborators and their backgrounds.

> **Researcher16**: “Yes, and this is a real problem once you move into interdisciplinary research. People think things are obvious when 90 percent of the people on the table say 'what the hell does that mean?'. [...] And that's it, people use terminology completely different [...]. And, finally, [this has effects on] how people approach problems. [...] The actual techniques that they use and the approaches will be very, very different. And again, it's not a problem, it's a challenge. You can sit there and you can watch people think 'And what do you do with that? Oh, I see it works, maybe I can do it that way'. So, there's a lot to be gained and a lot to be learned.”

Experience in collaborating with partners from certain backgrounds will make researchers aware of the differences, and a certain arsenal of solutions might be established. However, collaborators will always carry their epistemological 'baggage' and try to deal with problems the ways they are familiar with.

> **Researcher26**: “I mean, I suppose at one end of the spectrum, [engineers] want to sit down more carefully and think about things and model it very accurately, long equations, how things might work, exactly the parameters of it, you know. Whereas, sort of at the other end of the equation, you know, is more about, a little bit more distinctive about what we do is 'yeah, just make a chip out of here and throw some cells on it and see what happens.'”

The instance when differences become problematic is when collaboration can be perceived as difficult and its advantages turn into disadvantages. The most common problem seems to be an unawareness of fundamental differences, which can cause miscommunication.

> **Researcher24**: “[W]e have completely different sets of language. And that can cause confusion because I think I'm being clear and concise, because of the language I'm used to using, but it's not a language they're used to understand. [...] There has to be a reason why they need to learn it. And a will from them to want to learn it because it will then advantage them in some way.”

Here, science governance plays an important role. On a micro-level, project administration needs to provide spaces for translating disciplinary expertise, or even for meta-communication, so-called 'trading zones'. These can help foster scientific collaboration in the project by raising awareness of differences and providing a rationale for why communication methods might have to be adapted, or why learning needs to take place. On a macro-level, science governance needs to support interdisciplinary learning and collaboration. I return to the role of learning later, as this is one of the main approaches of researchers for dealing with differences and problems.

As I mentioned before, differing approaches to research problems have been mentioned as another major source of miscommunication. This might affect the way researchers feel about their part in the project as much as it can influence the progress of the project. This apparently encompasses not only the achievement of results but also the requirement to achieve these results within a limited amount of time and with limited funding. When researchers refer to instances of their ideas not being considered, or they think they were not able to contribute, they display a lack of personal confidence but also a lack of faith in collaboration. This lack might have an impact on how they relate to the area of enquiry of the project. The following are two examples of problems arising out of epistemological differences. In the first case, the researcher constructs a situation in which methods proposed by him are considered to be inappropriate for the research project, apparently without any reason given (at a later point in the interview the researcher reveals that he had been given the reason for why the proposed method was not followed up).

> **Anonymised Researcher F**: "I suppose one difficulty is in... proposing solutions to problems that I think might be workable and [laughs] the engineers probably disagree with, or don't follow up. So, I suppose that's the only difficulty. I found myself wondering why. Whether the approach I suggested is such a bad idea or whether it would be achievable."

In the second example, the lack of knowledge due to the application of a model chosen by collaborating partners and being outside of the researcher's own expertise leads to exclusion. The researcher feels unable to contribute to the final stages of the project.

> **Anonymised Researcher A**: "The interpretation is in the model, it's what model you've used, isn't it. [...] And I mean, they know it better than I do. I don't know enough physics to tell them this or that might be a wrong model."

These two examples reflect the *practical* nature of differences, of how methods and models can test the commitment to collaboration. Differences of a more 'philosophical' nature feature in the general conduct of research (see for example the quotation by Researcher26, p.150). This difference does seem to be profound, as a biochemist mentioned a similar difficulty of dealing with engineers.

> **Researcher12**: "They don't tend to get to the point as quickly as I like to get to the point. They tend to, kind of, talk in abstract and then talk around things, and then suggest possible things for the future, and I have to keep trying to pull them back and say: 'yeah, OK, that's fine and great, what about this here now? What are we doing with this here now?'. And then they kind of tend to wander of again and [laughs] I'm trying to get them back, to focus."

Epistemological differences constitute a coherent issue of collaboration: demarcation. Scientists look at research problems from a distinctly epistemology-rooted perspective, often connected to their wider disciplinary affiliation (*belonging*) but also negotiated with their actual specialisation (*practice*). The results of multi- or interdisciplinary research might even be contested in how much they belong to a certain disciplinary framework (cf. Strathern 2004). The two following quotations provide evidence for the strong disciplinary contest (still) enacted in NST.

> **Researcher14**: "There are very big conceptual differences, yeah. [...] And it comes down to experience more than anything else in most cases. Yeah, there is a lot of language problems. There is also a problem about [demarcation]. But sometimes I think that if they [...] were willing to step outside the discipline a bit more, then advances would come quicker."

> **Researcher26**: "Then, clearly, there is an inertia of knowledge that you almost have to overcome."

However, this 'inertia' of knowledge needs to be managed (governed) to make collaboration feasible. Apparently, advantages outbalance disadvantages, as most scientists I have interviewed seem keen to collaborate. Responses also indicate that they attempt to deal with differences and emerging problems.

*Managing Differences*

In that regard, four different but often closely connected approaches have emerged from my data: (1) relying on experience; (2) simplifying and explaining terminology and research results; (3) focusing on the scientific content of a project (which in turn requires awareness of existing differences); and (4) acquiring new knowledge and/or skills. At least three of these tactics have a clear element of learning. They can be characterised according to their differences in adapting to and/or accumulating knowledge and skills: adapting own specialisation for research partners; adapting own practice from research partners; or adopting/integrating relatable epistemological elements. The overall strategy of these four approaches relies on realising differences, acknowledging different specialisations and skills, and on accepting diverse ways and kinds of contribution to research.

> **Researcher11**: “[W]e don't have to be experts in everything, that's how we deal with it. As long as we have a basic understanding [...].”

> **Researcher16**: “We don't necessarily treat people from other disciplines as mentally subnormal. [...] Research scientists in any discipline, we are all pretty much on a level plain field. Their speciality, they are just as clever as me [...] just in a different area.”

The first tactic, relying on experiences in collaboration, is made up of two elements: to collaborate with same partners again, and to draw on previous experiences made with certain epistemological backgrounds, to be aware of differences and of potentially adequate strategies to deal with these.

> **Researcher7**: “But more often than not, the people we collaborate with have already collaborated in the past with people from chemistry, and they would understand more or less what we're talking about.”

> **Researcher11**: “[Y]ou tend to work with people that you worked with before. And that's not unnatural because I think you demonstrated that you can collaborate and so on.”

The second approach is to simplify language and ways of conveying specialised data. A common tactic to bridge language gaps is to break down meanings, or avoid difficult aspects.

The approach here is to change the method of delivery.

> **Researcher2**: “I try to keep the beginning quite simple in order to engage people into my presentation. And then later on I will give more details in a way that I may repeat myself twice or three times with different words or expressions [...].”

> **Researcher20**: “We try not to use terms that we think would be particularly specialist. And also we'd be willing to explain things if you're asked.”

Another way of dealing with these open differences is to explain and discuss contents on a wider basis to provide a more sustainable ground for understanding in collaboration. Although simplifying appears to be a common tactic in overcoming problems, it has limited value. In fact, my data suggest that most respondents do not rely on only one or two tactics in their overall collaboration strategy, but view these tactics as complementary. Simplifying terminology and individual research results can only have effect if contextualised by referring to the project aim as well as to partners' allocated research aspects. As collaboration evolves around addressing a certain line of enquiry, researchers find it adequate to keep the focus of communication on the problem and thus provide a context for their (social) collaboration as well as to the issue at hand.

> **Researcher8**: “Well, I think it's a matter of 'keep asking questions', basically, it's to keep bringing people back to the problem.”

> **Researcher9**: “[N]o different emphases will be what make the collaboration work.”

> **Researcher21**: “I would just make sure that what I'm saying would be very much focused on what [the] problem was [...].”

The third tactic, focusing on the project aim, features strongly in the accounts of my respondents. But this requires a shared understanding of the problem and its approaches. These elements have to be clarified to render this tactic meaningful. Connected to focusing on project aims is to translate 'raw data' into chunks of information considered adequate to the task of collaborators.

> **Researcher17**: "*You only need to know as much as you need to know.* In the end of the day, I don't need to know that much. I just need... the thing. From my point of view. And then they don't need to know that much, either. They don't need to know the whole thing, they just need to know enough to... make sure their understanding is clear enough to work on the bit that they're working." (emphasis added)

> **Researcher19**: "You don't have to explain something so that person can then sort of do the work. You just have to explain something to get a point across. So, if we want to make something we don't have to draw the whole structure out. When you just draw like a little cross-section and 'this is a potential problem' and... That's how we come over it. So, as long as you get the basic idea over it's not really a problem."

In an observation I made during the annual meeting of a large international project, I noticed that this strategy can still harbour many difficulties. Contributing partners might not be aware of the particulars that other partners presuppose. An atomistic approach – 'to know only as much as one needs to know' – can produce difficulties in terms of understanding the individual contribution or even the whole project, potentially even the eventual application in the real world. This might apply less to project initiators and administrators, but more so to lab-based researchers. At the same time, it will have an effect on how the non-scientific and non-technological aspects of the research project are perceived, if they are perceived at all.

'Atomism' can also limit the element of learning, central to the fourth tactic of improving communication and collaboration. Learning is a constant part of research life, influencing the *practice* and *strategy* dimensions of identity. Some of my respondents mention that they feel it is necessary to acquire further knowledge and skills for collaboration. There are diverse approaches to do so, ranging from asking colleagues if a certain basis of understanding exists to auto-didactically acquiring competencies.

> **Researcher18**: "The best is to learn yourself. Take a book and read and understand, yeah, because [if someone] just tells you, it could go in and then out."

> **Researcher22**: "[I]f I have a problem with something I go and ask them, you know. [I]t's a waste of my time [when] somebody can tell 'this is why this is not working' in a second."

> **Researcher25**: “For me, it took a lot of reading of physics papers and physics books to try and see what he was talking about. [...] I had to go and do maths, a little bit, so I could understand him. [...] I couldn't do the maths myself, but I had to understand what the maths was.”

Especially in the accounts above – and relating to the tactic of relying on experience from previous collaborations – an element of outlook towards future collaboration is involved. Being able to understand researchers from different backgrounds will help to collaborate in the future.

The four tactics of crossdisciplinary collaborative research illustrated here show the variety of approaches to collaboration. They cover a broad spectrum of engagement with partners of different (cross/disciplinary) specialisations. A strong element emerging from the data are the aspects of experience and learning, which are part of any research but show a particular potential to improve translational, interdisciplinary competencies in crossdisciplinary collaborations. The advantages of collaborative research apparently outweigh the efforts necessary to render communication meaningful and research compatible. Crossdisciplinary collaboration emerges as integral to NST research.

*Impacts from Collaboration*

A significant element of crossdisciplinarity featuring in the collaborative process of epistemological 'clashes' is the impact on researchers' specialisations. Communication across differences, once it takes place, will yield consequences that can lead to learning. The effects might be perceived as limited or even of a more latent nature. Nevertheless, crossdisciplinary collaboration seems to have impacts on most if not all participants.

> **Researcher7**: “I'm sure that you get some sort of influence from working with people with different backgrounds. What exactly that is I don't know.”

> **Researcher12**: “It's been a much more smooth transition than a step-change into different practices and learning different ways of doing things.”

These effects are described in these quotations as something diffuse, as part of the incremental process of science. My data suggests that researchers are aware of a constant learning influence from collaboration. These impacts seem to be considered in a comparative way, taking on board those aspects that are seen as helpful and as making sense in relation to the individual epistemological background. The processes taking place here are of a more (comparative) interdisciplinary nature as exchanges between the epistemological realms influence individual researchers' specialisations.

> **Researcher20**: “I think that slightly different outlooks work very well because you can then learn a great deal from your colleagues, get new ideas and new insight.”

At the same time, the differences might generate a more profound understanding not just by sharing or contributing individual expertise, but by also exploring questions that might arise out of ignorance or the shared feeling of 'non-knowledge' in a specific area or field. There appear to be quite a number of such unvoiced and unanswered questions in NST, despite or even because of the confidence some researchers have shown when discussing the field.

My data suggests two complexes arising from epistemological clashes: one more practical and one more theoretical complex. Expanding one's knowledge and skills by realising which techniques and approaches are feasible for certain problems or in specific circumstances, or by realising that some might be useful in future research, portrays the first complex of impacts. Here, the practical component is prominent as the transferability and applicability of techniques and approaches is emphasised.

> **Researcher9**: “You get to understand more about what's achievable and what [approaches] are available to do in projects of that kind.”

> **Researcher19**: “I've come across this [technique], which I've never used but it was on one project and so I've understood how it worked. [...] And what I'm sort of trying to run as a project now is sort of developing a probe [using a similar technique]. So, you might not use it, but [...] the knowledge is in there somewhere, and then, because you keep coming across it you sort of build on it. [...] It would probably take me quite bit of effort to actually do it [myself]. But I know the people.”

The researcher might or might not be able to apply a specific technique but already the awareness of how certain processes work can provide ideas for further research. Another aspect here is establishing links with colleagues who work in areas that might become, or are already, relevant to individual research. This is not so much a directly epistemological impact but the awareness itself may contribute to further crossdisciplinary research projects and the more theoretical aspect of impacts.

The second major complex is theoretical, characterised by realising new areas or fields of interest that might eventually lead to research projects in those areas. The researchers can expand their outlook and feel confident to work in related but different areas, or look at diverse aspects of a specific field.

> **Researcher25**: “[I]t does give you more confidence, that's the thing, isn't it. And, once you've read around things a bit and worked with slightly different stuff, you're confident to go a little bit further into it. [...] Okay, I've worked with this protein, so now it's not so scary for me to think about working with another protein out of the blue. Or even to think about going and isolating my own protein.”

This is an almost synergistic element of impacts. Problems might be realised that were hidden before, approaches can be utilised to results that might not have been considered before. The combination or selective uptake of epistemological elements, in as far as these fit in with individual specialisations, might even open up new fields of activity for the researcher.

In summary, crossdisciplinary collaboration apparently plays a vital role in knowledge and technology production in NST. This production relates to project aims, but also to learning processes, be they intentional or accidental. Although science generally remains disciplinary structured, and scientists identify with established disciplines, the practice of research in NST necessitates and brings together diverse disciplinary expertises. My combined findings from the last chapter's enquiry into identity construction and this chapter's contributions to understanding collaboration so far suggest the following understanding of disciplinary in research practice: researchers' specialisations become increasingly interdisciplinary (with a strong comparative element), whereas collaborations tend to remain multidisciplinary. It is researchers who negotiate the main burden of translational research individually, supported by being exposed to and possibly learning from collaborators' expertises and approaches.

## 5 The Role of Communication and Personality

Organisation of exchanges; the significance of personality for research and research identity

In the previous sections, an element has been surfacing every now and again, which is one of the most basic but at the same time one of the most critical aspects of collaboration: communication. The differences of an epistemological nature might be negligible or might be severe, the scientific understanding could be relatively easy from the outset. However, if communication fails, aims might not be consensual, approaches not negotiable, results incompatible. In the accounts of my interview partners, one seemingly minor and definitely non-scientific aspect of communication has been emphasised in some, or been of a subliminal nature in others: 'personality'. This aspect seems decisive for collaboration to work on a very basic level.

> **Researcher9**: “I think, even a colleague with a similar interest or expertise, it can sometimes be as hard working with those than working with people from different disciplines.”
> **MW**: “And why do you think so?”
> **R9**: “It's the personalities.”

Personality apparently plays a more important role than expertise or the disciplinarity of a collaborator. Respondents point out that certain character traits or personal behaviour can render collaboration very difficult.

*Individuals Collaborating*

This can refer to the administration of a project in as much as to research. Project coordination relies on trust, on being able to rely on partners to contribute to their allocated tasks whilst adhering to the time schedule and the financial budget. At the same time, the manner of coordination and delegation can provide difficulties when demands and expectations are issued in ways that might be considered inappropriate by those receiving them. It is respect that collaborators expect from their partners, both personally and for their contributions. Similar issues occur between research partners. Strained relationships are described as having a considerable effect on the project and its progress. If partners cannot work together or seem to fail to set up a mode of functional communication, a project might fail due to social, and not scientific, reasons.

> **Researcher12**: “I think that if there was any sort of difficulty with dealing with people like, kind of, falling out, if you like, it would be difficult to get back on track, because I don't find it easy to do that.”

> **Anonymised Researcher B**: “I wish you picked a different example. This project is actually suffering from a lot of infighting and back-biting just at the moment. [...] That's just various personality-clashes [...].”

*Personal Acquaintance*

On the other hand, knowing people personally will render collaboration easier, both in finding partners as well as in conducting research within the project. This applies especially if the tasks are closely linked to each other so that a considerable amount of time will be spend on coordinating research and meeting up.

> **Researcher14**: “I think [...] it works quite well, but that is entirely down to personalities and people. I think if the group of people works well together, then the project works well together. If the group of people don't get on, then no project is gonna work.”

> **Researcher16**: “I try to collaborate with people I can go to a pub with. Because you're going to spend an awful lot of time doing an awful lot of work very close together [...]. It works much, much better if you actually get on personally. [Personality] is the most important thing in collaboration [...] because otherwise it just becomes that little bit too formal, and everyone sticks to the rules way too much, and I see nothing happens.”

One respondent specified that he would want to work very closely with those partners who are actually doing the practical work, in his case the engineering for a technology that he provided the fundamental research for. Here, the social and the scientific meet. Social preferences merge with scientific expertise and interests. Thus, the emphasis on amicable relations with partners, and the apparent preference for informal working environments (see below) might be understood in line with an expanded research identity. It would indicate that researchers include social aspects into the construction of research identity as something required for successful research collaboration. This might appear to be obvious, but considering the boundary work of researchers regarding societal, or public, sectors, then it would seem surprising that social elements are indeed perceived as being influential for research.

*Communication Aspects*

Depending on the scope and context, but also on the funding, the size of a project will vary. The larger a project, the more it becomes formalised and administrated. Obviously, this will have an effect on how communication is organised. Projects of significant spatial proximity, such as with partners across Europe and beyond, will make it difficult to have many meetings, or even informal ones. Large projects are usually split into work-packages, where each package will contribute one aspect to the overall problem or aim. Not all work-packages will interact with each other, limiting the contact to project partners even further. These partners, however, might not actually be collaborators in the narrow sense of the concept as their work will only indirectly affect the other.

> **Researcher8**: “I think it's three work-packages [that interact very closely]: our own work-package [...] which deals with the sensors themselves; and then [another one], which is to do with the immediate electronics that our sensors are basically connected to, and are controlled by. People are doing instrumentation on that. And then there is another work-package [...], they deal with the liquids, the liquid delivery side. And liquids have to be delivered to our sensor, containing the material that we are aiming to sense.”

However, many of my interview partners tend to prefer informal meetings over formalised ones. Small projects, and especially close proximity between local partners, will make this more likely. In most projects, there will be both informal and formal communication. Formal meetings are less frequent, but regular. During these meetings aims, techniques, approaches and problems are discussed, there will be reports on progress; and a general coordination of the work-packages can take place. Formalised ways of communication outside such meetings, which are far more frequent, encompass email, phone and written reports and studies.

> **Researcher12**: “[T]he projects we are working on now are generating a lot of [...] information, a lot of e-mails, a lot of reports, a lot of market studies, a lot of technology studies. So, those are always coming across from the other partners.”

> **Researcher16**: “We meet up probably four times a year, formally, where we all get together and try ideas around. [Usually we use] e-mail and the phone [...].”

These meetings are important to bring together all strands and contributors of a project, and to possibly provide the overall picture for the scientific endeavour. But such communication can prove difficult at times, for example when research results or questions are complex, especially via the phone or in emails. Here, the first aspect of personality comes into play, the advantage of talking to a partner face to face, thus rendering communication clearer.

> **Researcher18**: “Of course, some data you can't just email and tell [your partner] 'look, this little peak' [because] then he sees so many peaks he doesn't know which one to look [at]. So, you have to show, you know. It's easier face to face.”

> **Researcher24**: “It's easier to sit with someone and say 'I don't understand that, draw me a picture'. And it's real time, rather than you send an email one day, you get a response the day after, and then you're out of the office and then... So, it takes you weeks to have a conversation. And that can be, that can make it more difficult. [Y]ou find yourself writing very long emails, that go on forever to try and be detailed enough, and then it just becomes too much. [...] you can feel that's a barrier when you're doing these things by email or phone calls with someone who is more distant to you [...].”

Communicating personally with partners seems to improve the way that collaboration is perceived, to provide 'pleasure' in dealing with colleagues. The process of research, then, is not based solely on the so-called hard facts of science and the scientific method, but also on the social competencies of its actors. At the same time, email and phone might be quick and easily accessible means to exchange information. But this information will remain superficial, as will the transfer of understanding due to the complexity of both research and its conduct. Here, the social component of technology becomes apparent.

The informal exchange in research, then, seems to help make the process smoother, but also more fruitful, as issues can be discussed in a more relaxed environment over and over again if necessary, and for as long as the partner might be willing to. Such more casual, informal environs to exchange, clarify and learn might possibly lend the factor of human error or limitations a more forgiving note in the scientific context.

Working more informally and closely with colleagues also incorporates a structural dimension. The more partners interact, and the more their research is linked, the more integrated does a project become; and potentially the more integrated and substantial will be research results.

> **Researcher20**: "When researchers are far away, the boundaries need to be much more clearly defined. Things need to be split more formally into packages of work. And then it's really like a series of parallel sort of semi-detached projects where there is an exchange of information. I think if people are nearby, or if there is an exchange of personnel [...] then it becomes more integrated. [A]n interchange of people I think is necessary really to produce an integrated single project rather than sort of related projects."

The data discussed in this section shows that structural interdependency between projects seems to be enhanced by the social connectivity of collaborators. Many of my respondents feel that personality is a strong factor in research, making collaboration a better research experience as well as scientifically more successful. Accordingly, the project coordinators among my respondents emphasise that interaction needs to be encouraged and fostered in a research project. If the personal connection is missing, the scientific work might be affected.

> **Researcher14**: "We're working on a big one at the moment with fifty partners, and I don't think I have talked to anybody else in the project for a long time because it's just too big. You just can't keep that going, and I think that project is not going to be as successful because it's too big."

## 6 Summary

In this chapter, I have explored the mechanisms and significance of crossdisciplinary collaboration in the academic-scientific research process. Collaboration might indirectly be described by some of my respondents as a necessary evil, but in their accounts research collaboration eventually comes across as being a significant aspect of research life, particularly in regard to the progress of science. In the case of NST especially, collaborative work is described as necessary to complement expertise and to gain access to research infrastructure such as equipment and funding budgets. Many scientists feel that collaboration emerges on an *ad hoc* basis. This takes place mainly through dedicated platforms of exchange and coordinating project-meetings, and less so 'at the lab-bench'. However, there are certain strategies in place, scripts of a generic kind, to participate in collaborative projects. Some of these are (1) taking advantage of funding opportunities; (2) furthering individual research interests by exploiting partners' expertise; and (3) directly using networks to find potential collaborators as well as novel research areas and ideas to address. In that regard, researchers would appreciate a more formal organisation in support of the emergence of collaborations, while still remaining in control over decisions regarding research partners and research aims. However, this seems increasingly undercut, on one side, by funding requirements that, on the other, might contradict the general structure of academic science. For example: costing centres being located within strict disciplinary boundaries render crossdisciplinary research sometimes rather difficult.

Dealing with difficulties that render collaboration advantageous – in managing epistemological differences – is an aspect that many researchers seem to try to address. In doing so they rely on various tactics in an overall strategy of focussing on personal research interest and by playing down difficulties that might refer to the scientific nature of the collaboration. The science in projects seems indisputable, the approaches to it, however, are very much debated. Scientists feel far more strongly about the social aspects of collaboration: being able to communicate their meanings; being aware of and accepting differences; and making an effort to manage these to progress the project. To do so is to work better with partners on a personal level, and to respect the disciplinary identity as well as their practical expertise. However, the research identity of partners seems not fully understood or explored.

Personal identity provides the framework for approaching others' contributions and their 'exploitation', thus the disciplinary background remains of a directing and influencing nature.

This kind of strategy does seem to work for scientists in an academic or, more broadly, a disciplinary structured environment. Difficulties of a specific structural nature, such as between the epistemic cultures of academia and industry (programmatically illustrated as progress versus commerce in scientists' accounts) might arise. This happens when the research-focus is shifted and the production of knowledge and/or technology becomes embedded within both strategies and aims that are of a not originally academic-scientific nature. Issues described as non-academic (but also non-scientific) are, among others, the notion of social sustainability and commercial exploitation of expertise and knowledge production.

In the next chapter, I further examine academic knowledge production in the context of societal tensions of non-academic and non-scientific aspects of knowledge and technology.

# Chapter 6: Academia and 'the Real World'

## The Non-Academic and the Non-Scientific in NST Research



### 1 Introduction

In chapters 4 and 5 I examined how scientists understand the field of nanoscale research; how they construct their identity as researchers towards and within NST; and what role crossdisciplinary collaboration in NST has for them. My analysis there focused on the disciplinary construction of NST within academia. In this chapter I expand the analysis of aspects of NST research practice that featured only as secondary before: non-academic and non-scientific aspects. These are integral to my respondents' accounts of nanoscale research, influenced by the general narratives and debates around NST, but also by science policy (governance) and accountability mechanisms in academia.

In the previous chapter I proposed that crossdisciplinary collaboration has become a major pillar of academic research. It is an indicator of its progress in the way it is conducted. Collaboration affects the scope and complexity of research potential. It also influences the emergence of academic institutions such as 'interdisciplinary' research centres, and of increasingly crossdisciplinary research specialisations of scientists. Knowledge production in crossdisciplinary collaboration, however, has to negotiate between different epistemic (theories, models, methodologies) and institutional (procedures, good practice, aims) scripts. In addition, researchers provide their own accounts regarding means and ends of research (views on what science and research are about).

In contemporary research, science practice incorporates interfaces with scientific and non-scientific colleagues in academia, but also with non-academic actors. The aim of this chapter is to examine how scientists reflect on non-academic (but still scientific) and non-scientific aspects of their research, and how this features (and impacts) in the construction of their research identity and collaboration. First, (section 2) I provide a context to my analysis in this chapter by briefly discussing societal agencies of knowledge production, to then examine (section 3) how my respondents reflect on their relationship and collaborations with (non-academic) colleagues in industry. This partnership is prevalent in NST research in regard to technoscientific and science policy requirements. In the following section (4) the focus of my analysis lies on 'non-scientific' (or non-technical) aspects featuring in the research accounts of my respondents. The aim here is to explore what role scientists attribute to non-scientific aspects of research, and how they translate these in their research practice. In the final data section (5) I provide an example of how non-scientific aspects influence science practice and the presentation of research by considering research funding again. This is of particular interest in the case of NST as narratives of the field incorporate high financial expectations; and since 'nano' has been described as a label by many of my respondents (chapter 4).

## 2 Knowledge Production in Society

In the context of a 'Mode 2 society' (Nowotny *et al*, 2001) and the 'co-evolution of science and society' (Schot and Rip, 1997), knowledge production – and within it research collaboration – does not take place in academia alone, but in and between many forms of institutions, which influence one another in diverse modes and manners. Commercial businesses, non-governmental interest groups or non-academic research organisations, amongst others, produce knowledge in varying kinds of research influenced by diverse interests, scripts, and requirements. It can be argued that in collaboration the boundaries of these institutions are transgressed in order to overcome limits of knowledge, skills, infrastructure. During these processes, new hybrid institutions might emerge, academic spin-out companies or centres of research that are parented by science governance bodies such as the UK Research Councils, that provide commercial services. The blurring of boundaries is quite apparent in these instances where institutional agendas represent a fusion, or even synergy, of different sector-aims. Less clearly defined are the transgressions in cross-boundary research collaboration (between industry and academia) where different institutional agendas exist in an overarching and coordinating project agenda.

Drawing from the literature and my research data, I suggest that five societal sectors directly and indirectly contribute to the production of scientific (and technological) knowledge: (1) academia; (2) the commercial sector, particularly industry; (3) the public sector of non-governmental interest and research groups, such as environmental groups, charity trusts and consumer interest groups, which contribute to both the production of scientific knowledge in research and its interpretation in the context of societal interests; (4) the public sector of governmentally organised knowledge production and facilitation such as the Research Councils in the UK and policy-making agencies; and (5) the general public. In these five sectors knowledge is produced and used in different ways, at times considerably so. Interest groups, non-scientific governance bodies and the public interpret and apply scientific and technological information as and through information, education and products (consume). Their views then feed back to science via the media, science policy (academic, corporate or governmental) and funding (for example by which charities are supported and how they decide to spend their donations), but also in researchers' very personal impressions of how the public might view their profession, and how that might affect science policy and funding.

However, qualitative differences in knowledge production exist between *all* five sectors. One major difference lies in the thrust and motivation of research. Many of my respondents aim to understand and influence the material world in their research. Knowledge production in sectors such as industry and non-governmental interest and research groups seem to be perceived by academics as being conducted in reference to broader aspects of knowledge: social, economic, legal or environmental.

In this chapter I explore scientists' identity construction in relation to industry and the public sectors, expanding my analysis of crossdisciplinary identity negotiation from chapter 4 and inter-academic scientific collaboration from chapter 5. My data suggests that researchers construct a coherent group of academic scientists ('us'), thus demarcating themselves from other sectors of knowledge production ('them'). In this chapter the focus on 'them' is on industry, but to a certain extent academic social scientists, science governance and the general public are considered also.

In regard to non-scientific aspects of research I investigate scientists' views on the input social scientists and ethicists produce, which is basically an inter-academic discourse but nonetheless one of persistent 'otherness'. I suggest that my respondents' accounts negotiate social scientific approaches to scientists' research as being situated somewhere between academia and the general public, thus between two very diverse knowledge arenas. The focus on these collaborations is influenced by my participants' responses to questions on NST debates and experiences of collaboration.

## 3 Academic-Industrial Collaboration

On influences from industry and research competition

For my respondents, the focus for NST research collaborations seems to lie mainly on other academic institutions, and then on commercial businesses or industrial partners more generally. In almost no instances were public sector-spaces mentioned for research collaboration. This can imply an understanding of research within academia and with industry as being knowledge production *per se*, that is with a strong focus on scientific aspects and scientific epistemology.

This particular relationship between academia and industry is an example of problem-focused cross-boundary collaboration. It is an increasingly important element of contemporary science practice (cf. Jacob, 2001; Webster 1994). The basis for my analysis rests mainly on my experiences at NST networking events and research conferences; on on-going debates about academic science (for example Crespo and Dridi, 2007; Nowotny *et al*, 2001; Zimmerli, 2008); and on my empirical study of NST in the North-East of England.

Collaboration with industry and the impact of industrial research competition seem to have become two influential elements of academic research in contemporary science (cf. Crespo and Dridi, 2007). It can be argued that this has contributed to an increase of applied science and technology production in academia. This, in turn, necessitates increased collaboration across disciplines.

*Industry as Opportunity*

The commercial aspects of academic-industrial collaboration are not necessarily seen as disruptive. Indeed, extrapolating from my data, scientists seem rather inclined to include some kind of commercial focus in their research if it helps to acquire funding for new and experimental research. In fact, European Union-supported projects in academia often require industrial collaborators, thus creating incentives to cooperate with industrial scientists on a more regular basis by rendering collaboration a condition for funding. On the other hand, decreasing state funding has been substituted with commercial cooperation and finance (cf. Etzkowitz and Leydesdorff, 2000; Webster, 1994), that is for as long as commercial interests do not 'interfere' with what academic scientists perceive as their 'genuine' scientific endeavour (the pursuit of understanding the material world expressed in individual research interests).

Apart from access to funding or various requirements on academic research, further rationales for working with industry are reflected in my respondents' accounts. Some emphasise that applied expertise from industry is desirable and very helpful, whereas others primarily consider collaboration as a means to access equipment. Two of my interview partners welcome the managerial research style that a commercial agenda requires, focussing the project and pushing it towards short-term results. Both are involved in the management of research projects. Others, however, criticise a possibly short-sighted focus, and the more stringent organisation of commercial research as limiting tangential enquiry outside the project's focus. These objections hint at an understanding of academic research as qualitatively different from industrial research practice, or even generally outside of academia, allowing and even encouraging research digression.

However, the mode in which research in academic-industrial relationships is conducted seems to provide a different context for academic research, especially interesting here for the outlook of scientists. This relationship is influenced by a variety of factors, some of which I consider here. First, research ideas and issues are often supported or part of the agenda of academic institutions. This will have an influence in what partnerships or research can be pursued, but it also offers opportunities to pursue research not funded otherwise, especially in view of the declining ratio of state funding (cf. Jacob, 2001; Webster, 1994). Second, time-scale plays a different role for academic and industrial researchers. This connects to the issue of research tangents mentioned above, but can turn into an advantage for research stringency and turn-around of findings. Third, commercial applications can provide a context for scientists' interests in technology, or even focus research into applications. Fourth, technology transfer also contributes to the scientific credibility of scientists (cf. Packer and Webster, 1996), and seems to bolster claims of researching *for* society.

*Academia's 'Pure' Science in Decline? A Comparison*

These factors can influence the individual outlook of academics, away from a focus on the scientific *l'art pour l'art*, that is 'investigator-driven' science (Esparza and Yamada, 2007), towards science not only as a career of knowledge production but as a career with profound technology transfer through patenting and creating spin-off companies, and possibly wider social recognition. These social aspects of science contribute to rendering the notion of 'pure' science, disconnected from society in its conduct and driven by aims of understanding and producing knowledge for their own sake, obsolete. The notion of 'pure' science, producing 'neutral' knowledge without societal interests, tends to be quite strong in the boundary work of academic scientists. My data indicates the construction of an overarching identifying aspect of 'pure' science in contrast to science conducted in the context of societal interests – such as by industry and interest groups – which are implied as conducting 'impure' science, 'muddied' by societal agendas.

In the previous chapter I quoted Researcher7, referring to the notion of scientists being "worried about [...] their reputation as being a serious hard-core scientist", which implies public – in addition to peer – recognition of their work and is a sentiment found in many accounts of my respondents. This is implied particularly when scientists contemplate the role of their work for the progress of society, which is a rather socio-positivist perspective often ignoring or down-playing potentially adverse societal aspects of science and technology. However, this and other instances in my interviews show that the societal influence on science practice is not insignificant. Indeed, I argue that the notion of 'pure' science is mainly an ideal of a time less spent on administration but more on research.

My reference to the world of art in regard to the notion of 'pure' science illustrates a parallel between the two worlds of art and science. Art reflects on theological, ethical and social issues. At the same time, it is also a profession and provides artists with the economic basis of their being. Societal recognition is an additional aspect promoting acknowledgement and spread of the artist's ideas. The modern art world has tried to give the impression that art is an agency unto itself: *l'art pour l'art*. Art, Abbing argues, has been described as living from 'gifts', thus diverting attention from its economic dimension (2007:47). This has been reflected in romanticist metaphors of the 'poor artist' or the 'estranged genius' since the 18th century. The presentation and interpretation – thus 'application', in reference to science and technology – of art sometimes seems segregated from their point of origin in that artists provide for elites in the context of 'creation as self-actualisation'. Contemporary accounts of historic artists' lives, however, rarely pass over their need for financial gain.

This does not mean that self-actualisation has no place in contemporary art. On the contrary, 'art-for-art's-sake' remains a significant model of preference (cf. Caves, 2003), in a similar way that scientists' research interests provide the drive for further research and innovation. However, the art sector has (been) opened up over the course of the last two centuries, as has the world of science to the non-academic sectors. Contemporary artists seem to generally embrace the notion of generating economic and social as well as cultural capital – its defining vantage point. Art as an activity has acquired a more pragmatic dimension (*ibid.*). We can find evidence of this in the greater variety of engagement with art; the establishment of public art institutions; and the wealth-generating art-trade sector of auctions and galleries. Here, too, have boundaries of institutions been transgressed, and we find art education in schools, universities and 'life-long learning' centres. Art moves into the public space, such as in street art and in advertising. The Japanese artist Takashi Murakami emphasises this by stating that “[o]nly those artists who have an ability in marketing can survive the art world” (cited by

Brehen, 2002:186).

The world of science, particularly academic science, shares many of these elements of change with the world of art. The aspiration to provide knowledge and technology for society provides a rationale for academia. Professionalism in science conduct (science as a vocation) and expectations of recognition by peers and society generally have changed science practice. Science in the public eye (TV shows, consumption of products) draws attention to science practice. The marketing ability mentioned by Murakami can be translated into scientific accountability processes, particularly for funding processes. Scientists do not only explore and aim to understand the world, they aim to equally address issues of society through science and technology (cf. Nowotny *et al*, 2001; Zimmerli, 2008).

'Pure' science as a strong notion in science (cf. Moriarty, 2008) seems to be challenged in science practice. However, as becomes clearer in the following parts of this section, scientists continue to refer to this ideal of academic science. I aim to identify the reasons for its perseverance but also for why it has become an ideal incompatible with cross-boundary collaboration in contemporary science practice such as NST research. This connects to the question of how academic scientists negotiate their identity within collaboration with industry.

*Negotiating Academic Science in Collaboration with Industry*

As I indicated in the previous two chapters, experiences of collaborations have significant impacts on how researchers identify themselves and negotiate their motivation. Several rationales exist for scientists to consider working together with researchers based in industry, and thus endanger the ideal of 'pure' science. This collaboration is likely to be supported by the similarity of researchers from both sectors in regard to their scientific outlooks and training. The institutional agendas and scripts differ, however, with industry having a strong commercial rationale that requires product development. Nonetheless, some academic institutions or academy-based organisations share the commercial outlook in research with industry, and competitiveness exists on both sides. The possibility of working together with partners who want and need to apply science outside the laboratory seems a strong motivational aspect for collaboration with industry. Academic scientists can test emerging ideas, see their research applied, or take their research or technology further towards application as the following quotations indicate. However, it is interesting that respondents who mention collaboration with industry, talk mainly about the benefits industry gains by working with academic partners, instead of their own benefits. They seem to focus on a *contributing* nature of their relationships.

> **Researcher7**: “So, I think there is an advantage for industry [...], which is application-driven, to talk to people in academia, where maybe, you know, the original concept was [put] on a back-burner, and a few years later someone scrolls through the papers and [...] can go back and revisit it.”

> **Researcher12**: “We're basically looking at what's being made outside in a company [...] and testing what they are making.”

> **Researcher16**: “It's really interesting when we give [industrial partners] something, they come back and say 'we've done this with it'.”

These quotations suggest that researchers, whilst acknowledging their benefits, down-play these and emphasise their contribution in collaboration with industry. This can be part of accommodating research with evidently commercial objectives, which do not seem to be universally accepted for academic research. More on that below. Academic scientists apparently continue to uphold the ideal of conducting research for its own sake and disconnected from societal interests (cf. Moriarty, 2008) and thus *demarcate* academic science from industrial research. Although academic and industrial scientists share the scientific foundation, their institutional contexts and agendas (aims) differ. Boundary work becomes visible here, with academic scientists separating (their own) scientific research ('us') from commercial or other societal interests of 'them'. Academic scientists grapple with their context-embedding identity, that is with the construction of a research identity that attempts to clearly signify the emphasis on knowledge as part of the structural dimension. The focus of academic science is to produce 'pure' scientific knowledge, knowledge not changed through societal interests and agendas (as in industry through commercial interests). At the same time, recognition of the need for knowledge as well as funding from third parties (such as industrial partners) is implied for academic research practice. The physicist Philip Moriarty provides an account of the notion of 'true' academic science where particularly commercial interests from funders should be limited in their influence on science practice (2008). A public debate organised by the London-based think tank DEMOS in May 2008 included several senior scientists who supported the idea of 'true' academic science, or the notion of 'pure' science, despite being aware of the funding realities of contemporary academic science, or despite encouraging outside, non-governmental funding.

Although the commercial aspect might have permeated the academic realm, scientists' acceptance of it seems rather limited for science practice. This might seem contradictory, but can be seen on different levels: (1) institutional requirements, such as business-like university administration, foster outside funding and commercial success of research; (2) researchers can translate this into acquiring funding for further research whilst negotiating individual interests; and (3) academic research itself is portrayed as providing knowledge and expertise for society. To render funding requirements and accompanying societal interests compatible with academic research culture, the contribution of academia to other societal sectors is emphasised. A strong contribution lies in providing knowledge through research, a second through education.

*Example: The Case Studentship*

Case studentships are an example of the educational contribution of academia's narrated societal role. They bring together academia and non-academia in a training setting.

> **Researcher15**: "That [case studentships] is a way of getting interaction also. It's a way of finding out what industry need. [...] I suppose, most research groups have been steered into industrially relevant areas, you know, certainly over the last ten years or so. [...] Probably the biggest impact is with dealing with either researchers or engineers from industry, and seeing [...] what drives them. [...] That has a major effect on us and the direction that we have to take."

Case studentships are jointly organised supervisions of young researchers with one supervising partner placed in academia and the other being located in industry or the public sector. Here, the transgression of boundaries in knowledge production becomes very apparent. Both funding and knowledge – as in learning and researching – are coordinated and shared. Case studentships as a 'boundary object' in research have specific benefits. These show that influences of such collaboration go beyond the purely educational task. One benefit is realised in providing space for insights into different perspectives of knowledge and technology production for student, supervisors and connected organisations. Such a collaboration might help intermediate between the different research identities of academia and industry on an equal level (funding for training and knowledge). Institutionally, hybrid research organisations at universities and small, inventive start-ups can combine industrial research management and its product focus with academic research liberty. Another benefit is the production of knowledge that connects to interests of both the academic and the non-academic supervisors. For the student, practice-orientated work can provide sense and motivation for future research. Disadvantages lie in potential collaboration difficulties aggravated by the differing identities and agendas of academic and industrial researchers, possibly even further expanded by divergent understandings of extent and content of the learning aspect in the studentship.

Collaborative vehicles such as case studentships provide grounds for a fusion of the two above mentioned approaches, the focus on understanding the world and the contribution aspect in knowledge production, in understanding scientists' accounts and attitudes towards academia-industry collaborations. They link research practice with scientists' understanding of what research should be like by emphasising and reaffirming academia as the provider of scientific expertise for society. This includes the education of young researchers for industry and other public sectors.

*Demarcation of Modes of Knowledge Production*

Simultaneously, academic research and its outlooks or trajectories are influenced by industry in different ways. Researcher15 refers above to the 'need' of industry and the provision for these needs through education, collaboration in research, and consultancy. These provisions connect more than they separate, and differences in institutional contexts and agendas between academia and industry become less prevalent. Nevertheless, these two aspects still have an impact on the demarcation academic scientists negotiate ('us' versus 'them') since commercial and other strong societal interests in or around research render it being *not* 'pure' science. However, academic scientists attribute a status to industrial partners unlike the one accorded to the general public or social scientists, who have interpretation and explanation patterns very different to academic or non-academic science. Industrial partners create knowledge in a similar way to academic scientists. They usually have a background in academic education and are perceived as having disciplinary links like academic researchers. Both share a common ground.

> **Researcher14**: "[B]ecause we work with industry in that project [...] you have process engineers, plant managers, you know, a whole range of backgrounds there. People with physics degrees, people with chemistry degrees, [...] coordinating people, sometimes they'd have backgrounds in history, they're just project managers."

Therefore, another significant factor influencing academia-industry collaboration is that scientists currently researching in academia might have worked in industry previously, and vice versa. Communication with industrial scientists seems less of a dilemma than with the general public or with social scientists, because undergraduate training at university has been the same, as are the scientific foundations of addressing a problem.

Again, this does not imply that outlooks and general approaches to a project between project partners are the same or even closely similar. The institutional context of a researcher will provide scripts for conduct and research agendas, and influence the accounts that researchers construct on how and why research is being done. It also affects their personal research preferences. Working in academia will usually allow for a less time-focused and less application-orientated agenda than in industry. However, it does mean that academic scientists find it easier to understand their industrial research partners (both in regard to their scientific and technological knowledge as well as their methodologies and models) than scientists who work for interest groups, such as Greenpeace, with societal agendas which their scientific findings have to accommodate.

As an aside: Researcher14's reference to social scientists' managerial role in the scientific research process implies that they are not part of the actual knowledge production process. This implies a hierarchy and task-division of disciplines in research. Social sciences seem to be regarded as organising the scientific process, and as supplementing the translation of science for the public domain. This notion has surfaced in several of my observations.

The public sector is constituted by further *scientific* groups, which I have mentioned in the introduction to this chapter: charity-funded research institutions; research centres administrated by UK Research Councils; and other governmental and non-governmental research organisations. These might be seen as being similar to academic scientists, as are industrial collaborators, since the means applied are scientific, whereas the ends might differ greatly. My respondents have not explicitly referred to these other groups, apart from working on grants from Research Councils or charity organisations. Maybe they do not set them so much apart from academia in science practice, or their focus in collaboration is very much on industry. In any case, industrial scientists are narrated as close 'relatives' and collaborators in the progress of science. Whereas the public are represented as the opposite of science, relying on interpretative and non-academic understandings permeated with societal – and apparently 'non-scientific' – influences. This represents a demarcation process. Academic scientists narrate themselves as 'us', and all other groups as 'them' with the option of 'tolerating' some groups from the public sectors more than others. Industrial scientists, it stands to reason, are more tolerated than the public in matters of science and knowledge production. However, the perceived boundaries between academia and other sectors, even industry, are defended, represented in the very aims of research.

> **Researcher16**: "[W]e are interested in doing the understanding and doing the basics. Whereas [industrial scientists] are interested in making it work and 'when can we have it'."

> **Researcher19**: "If you go [into] industry you have to make a product, you have to [make] money [...]. If you're here you just want to explore new things […]."

Thus, although scientific research might be the mutual basis for both academic and industrial researchers, and although shared education of means provides a basis for mutual understanding, the conduct of research is portrayed by my respondents as being different, which adds another dimension to the general differences in epistemology I have described in chapter 5. Diverse disciplinary backgrounds carry their epistemological weight of models, theories and methodologies, which it might not always be straightforward to align to each other. Therefore, crossdisciplinary collaboration rests on patience and the willingness to negotiate. This second dimension is reflected in the perceived variations in researching. They supplement the identification process not just within the academic disciplines but also between 'competing' institutions of knowledge production.

The differences between academic and industrial research seem most significant when contrasting the contextual, that is, the institutional rationale for research. Whereas in academia knowledge production is still often described as trying to understand the world, the perception of industrial research there is pointed towards technology production for application and commercialisation.

*Diffusion of the Academic-Commercial Boundary*

Opinions, however, vary according to the experience researchers have of collaborating with industry, and with the agenda of their very own institutional setting. Some of the researchers I have interviewed work in academically based research organisations that provide services for mainly commercial customers and thus conduct research in the context of application. In reference to one of these centres and their commercial aspect, several of my respondents have stated that 'no proper' research takes place there. This might imply a certain disregard at least for academically based organisations providing services. On the other hand, internal politics also play a significant role in science, in particular in the evaluation of colleagues. The above mentioned attitude is likely to draw on the institute being somewhere on the verge between academic and commercial, and its opportunistic agenda in choosing its institutional context. It is an example of what Jacob calls “Mode 2 research institutes” (2001:85), where the traditional institutional boundaries of knowledge production are transgressed. It does differ slightly from Jacob's postulated cases in that here original research is mainly conducted by young researchers such as Ph.D. candidates and post-doctoral researchers, and that the institution is not a project-based, temporal entity.

Embedding clearly commercially driven centres in the university apparently creates some profession-related friction among scientists as research agendas in the shared institutional framework begin to differ considerably. New and emergent science and technologies provide a wealth-generating element for academia with some researchers embracing this more than others. This criticism is particularly strong when research is being perceived as a service for non-academic organisations, not so much in cases of patenting, which seems to be far more

accepted as part of academic intellectual property management.
One of the profound differences between academia and commercially-orientated researchers is the idea of research freedom or research breadth that characterises academia in contrast to commercially utilised research, also mentioned above by Researcher19 as the exploratory element.

> **Researcher8**: “He could have an idea, which is totally out of our normal range of work. And that could switch us into [...] going down a different road altogether. [...] You don't get that so much in industry because, you know, things are far more defined there, and industry has to make a profit and so on. Things are far more controlled in that sense.”

Once again, conducting research for its own sake as well as being able to digress, or follow tangents, are two elements that are portrayed as being at the core of academic research, of the idea of 'pure' scientific endeavour. One of my respondents, a project coordinator in an academic-industrial collaboration, has mentioned the difficulty of keeping academic collaborators to focus on their research tasks in order to fulfil project aims and deliver on time. It seems 'natural' for academic scientists to follow emerging research ideas within projects when the opportunity arises, even if this upsets the timetable. Research for the sake of deeper, or better, understanding – this can be seen as an aspect of the notion of 'pure' science conduct, since in any case knowledge will be produced that will be of scientific substance. It is the extent to which such digression is possible that sets apart academic and industrial or agenda-driven science, such as cancer research conducted outside of academia and funded by charities. Following leads, and thus slightly diverging from the timetable, is to be expected even in very applied research projects since it would be very difficult to apprehend every possible difficulty or *cul-de-sac* in research.

Despite agenda-related and epistemological differences between the academic and the commercial sector that are emphasised by some of my respondents, there is a notion of growing similarity between academic and industrial research in the increasing significance of research application and the economic capitalisation. The *critical distancing* of academics towards commercially focussed research does not impede the view that both sectors, academic and industrial scientific research, are significantly contributing to society by producing knowledge and technologies. Especially among the life sciences, I have noticed, the notion of the transgression of knowledge production across sectors is not so uncommon.

> **Researcher17**: “I'm not sure we can make such a clear distinction anymore as there's such a great amount of spin-out and patents and goodness knows what. There are a mixture of those things, I suppose is the easiest way to say it.”

Here, influences from the real world into academic NST are perceived, into academia as an institution of research, of education, and of business. These influences are more elaborated by researchers who have had positive experiences with industrial collaboration. Indeed, this is an indicator of how academia as a whole is undergoing institutional modifications, which feature as adaption of certain standards from outside academia (such as business management methods), or in emerging partnerships with spaces of research and technology application (such as hospitals). Academia itself shows strong societal interconnectivity, especially in elements relating to societal users and providers, such as university education, funding acquisition and research transfer (such as in licensing, patenting, consultancy). Research taking place within academia diversifies according to the institutional structures that emerge in 'Mode 2 research institutions'.

Again, the notion of 'pure' science is thus hollowed out by two parallel developments in NST: the change of academic structure (Mode 2 research institutions); and in science practice through cross-boundary collaboration with other agencies of knowledge production with societal agendas.

*Impacts of Collaboration with Industry*

One example of emerging new structures in academic research is stringent research management. In the quotations below, industrial standards in knowledge production are described positively. Although such accounts remain the minority, their simple existence provides evidence for changing attitudes towards industrial and, as such, corporate influences in academic science.

> **Researcher12**: “[T]he biggest influence is better reporting, better time-keeping, better scheduling, having to meet deadlines, which academic research, depending on funding source, has to do but it doesn't do it in quite such a, you know, a defined manner. There

> are better procedures when you're working with industry, in defining how to do things. How to monitor [...] progress, how to monitor success, how to instigate, sort of, risk analysis, fall-back procedures. Academic research, sometimes, thinks that you, like, burrow on ahead. Hit a barrier, bounce back from it, think about it and then burrow on ahead again. Whereas work with industry tends to always look at what might happen [...] different scenarios [...] they are much better organised to deal with contingencies."

> **Researcher24**: "With the project that we're in being commercially driven, that has also [had an impact]. And some people might argue that that's not a good thing. But I think it depends on where you want to go. But having a better awareness of the regulatory impact of things, but also on things like, things have to be manufactureable [sic], and they have to be cost-effective, and those sorts of things [have] been very useful."

Researcher24 indicates that academia does not simply copy industry's approach to research. Instead, some adaptation of standards may take place to help academia in the process of producing applicable research results such as technology. This may be less pressing for highly theoretical research or basic research. However, since academia relies on funding sources, and increasingly so on competitive third-party funding, new sources of funding are required. Some of these lie in offering commercial services to both academic as well as commercial users of their technologies. Although corporate methods might be introduced to the management of academic research, this does not mean that academic institutions simply adopt business-approaches from industry. On the contrary, the differences remain quite distinct. In the following quotation, the respondent refers to experiences made by universities that tried to copy the business model of companies. The researcher explains how they have adapted this to their very own model to be in line with scripts of academic research institutions.

> **Researcher15**: "[A] few years ago, the in-thing was to try many spin-outs. And now it's realised by some universities that's not the way to go. It's licensing, it's creating [intellectual property rights] and licensing."

Academic spin-outs are commercial businesses created by either individual researchers and/or supported by the university by providing funds, staff, expertise and infrastructure. There are still many such hybrid companies in existence, at times with the managerial staff being employed by academia as well. Yet, to run these businesses, researchers have to devote their time to contributing to and running however small the business might be. At the same time, if the university holds a financial stake in the spin-out, it can become a liability as many purely research-driven spin-outs do not create a profit for some time, if at all. This was the case with the start-up bubble in information technology in the late 1990s, which burst and left many investors and entrepreneurs fund-less. One further item of concern for the university may be that commercially contextualised research in spin-outs might not attract funding from organisations that would support academically based research. My respondents claim that academia is different in structure and agenda to institutions whose agendas are orientated along societal interests, such as commercial or public interest bodies.

My data suggests that the expertise of academia is perceived as being in knowledge production, not necessarily on the transfer of it into marketable applications. Academia, also from the side of its funders, seems mainly constructed as an institution of knowledge production and reproduction, whereas industry is strongly perceived by some of my respondents as being focused on application, marketability and profit generation. Differences in time frames, research motivations and research methods are narrated. It seems that academic scientists do not attribute individual research interests to researchers in industry. Instead, the scripts of commercial industry wash these out. This is one of the major differences constructed by academic scientists, as I have pointed out above: to be able to follow personal research interests. At the same time, academic scientists acknowledge that funding requirements and expectations from governance bodies and collaboration partners influence their research practice. They undermine the idea of a strict differentiation between academic and non-academic knowledge production, between a 'pure' and a societal-interest driven science. The differences here are, again, in the rationale for research, and as such in the understanding that researchers have of science.

Following on from the above made points, researchers might also *have to* follow modified institutional scripts in academia, which require collaboration with industry or the adoption of certain standards. Both academic scientists and research institutions have had to change their outlooks in order to legitimise the position of academia in society. It becomes a skill to be able to narrate these changes, but it might be seen very critically by some researchers. I used the quotation below before in the context of research motivation and drivers, but it also fits here as the respondent criticises the economic nature of academic research and its effects on individual researchers.

> **Reseacher11**: "And what drives research today is basically getting grants. And getting grants will depend on what the latest fashion is [and] many people [will] become 'butterflies', and they move from one area of interest to another [...] because that's where the money is. [...] I think you need to look at what the driving forces are. And the driving forces are driven by the institutions."

Here, the independence of academic researchers to follow their research interests is described as being jeopardised due to institutional changes and the increasing necessity for research to appeal to funding organisations by competing with other sectors of knowledge production. This presents further evidence that the notion of 'pure' science conducted in academia seems only an aspiration, and is at best a dated ideal of science conduct, which cannot be pursued in contemporary academic science. It also shows that academic research is influenced strongly by decisions and policy made outside the sphere of research.

*Example: Licensing in Academia*

However, the university itself has become a commercial enterprise. It is influenced by societal issues, such as student interests (see the closure of physics departments across the UK due to dwindling matriculations) or increasing cost and complexity of research leading to the implementation of stronger legitimation processes and scrutiny in research governance. Management in academia becomes more stringent and influences research practice. The instances of licensing and patenting are a sign of the adaptation process. Commercialisation of research and education due to the practical turn in expectations towards academia (productivity and efficiency) stand in relation to the increasing accountability for research in general, and funding in particular, that academic research has been facing since the early 20th century (cf. Deuten and Rip, 2000; Etzkowitz and Leydesdorff, 2000; Jacob, 2001; Rip, 2000).

Licensing and patenting are, however, also indicative of academia trying to sustain distinctively academic research structures even in the context of the transgression of boundaries in knowledge production (see Packer and Webster, 1996, on the different social worlds of academic knowledge and patent production). Training current and future researchers is one major aspect of the academic rationale. Another is to pursue research into areas and fields of enquiry that might not be conducted to such an extent in institutions of focused knowledge production (industry, policy-informing research institutions). The accounts of my respondents contain these tasks, which suggests that they help to affirm academia as a distinct societal structure with both scientific and social elements to it.

Licensing, then, can allow the separation of the processes of (1) knowledge production in research; (2) its potentially drawn-out development towards application in the risky world of business; (3) the potential generation of income by making a profit through licensing; and (4) producing further knowledge through development and application, which might be studied through the feedback from licensees. Although productivity and efficiency have become aspects that academic research has to incorporate and live up to, the natural, clinical and physical sciences seem not well equipped for contributing to aspect (2). The turnover from basic research to technology to marketable application has been mentioned as difficult in academia at a few instances during my interviews. Apparently, governance institutions take the same approach as evidenced in the requirement to include industry in larger governmentally funded projects. To develop and market applications requires investments into production lines and staff. It also needs stringent management based on marketability and profit, and on various legislations regarding workplace safety, product life-cycle safety etcetera. This would impair the relative liberty of academic research to digress, which is a significant aspect of academic research (cf. Martin *et al*, 2004). Through licensing, the focus of the university may remain on knowledge production whilst being able to finance research and education, among other things.

However, it would be interesting to see how well processes of licensing compare to processes of patenting. If these two were similar then the nature of academic science practice might here again be changed towards a more applied outlook to science via legal and other patenting requirements. These constitute a different negotiation system of science and research findings than is found in academic knowledge production and dissemination (cf. Packer and Webster, 1996). Two understandings of academic science practice can be derived from that for the analysis of academic-industrial collaboration. First, academic science practice becomes more complex by encompassing different negotiation arenas, and thus includes non-academic and even non-scientific considerations. Or, second, academic science practice is focused on research, whilst activities such as patenting and licensing constitute a different practice. This would render academic knowledge production processes distinct but connected to commercial aspects of research.

*Competition in Academia*

A further consideration here is that academic research is competitive in itself and, as Researcher14 mentions, “you're competing with the large companies” and other non-academic agencies of knowledge production. Claiming support for research; publishing papers; and presenting original findings on platforms of exchange are all part of establishing scientific authority, but also of negotiating the social aspects of science. Then, the industrial kind of competition is added. It is more clearly defined through research management. Researcher12 has referred to time and stringency being important factors for collaborations with industry in European Union-funded projects. There, research needs to lead to applicable and marketable results in the short-term. Therefore, the competition between academia and industry – and other public sector institutions – in the production of knowledge can be described as having effects on academic research on three levels: (1) on institutional decisions on what research foci to set and which services to offer.

> **Researcher15**: “One of the noticeable things within the last five or six years was that we were heavily relying upon [public] funding, and [...] how that was structured drove us [...] particularly towards the consultancy and serving regional [small and medium enterprises]. But, equally, it imposed a huge bureaucratic burden and framework on us.”

It will also affect (2) research management, as described by Researchers 12 and 24 before in that certain management standards may be introduced to academic research. Also, existing or felt competition can influence (3) research practice, for example by increasingly relying on crossdisciplinary and more integrated collaboration, but also by particularising projects with these becoming more temporary, emphasising the networking aspect of research.

> **Researcher12**: “What we've done is we've taken the stage between working in the lab and actual commercial reality to work in physical prototypes, which can be, you know,

> handled, which can be made, and which don't just work in the lab with big equipment, with lots of wires. We have to talk about making small circuits, connecting them to signal processing [...]. What we do now is talk to [partners] from the beginning. Not getting to a stage and going back to talk to them, but talking to them in the beginning and going forward. So, that's very different."

> **Researcher14**: "[I]f you're gonna be credible on your working on a technology area, like microelectronics, you're competing with the large companies, the 'Intels' of this world. They have a group of people with different backgrounds working together, so if you're gonna compete you have to be the same sort of group. If you can't, then you're gonna do your own little thing, and that might be good stuff, but you're not gonna be able to be, sort of, recognised as being a major contributor to the area."

I have used the quotation by Researcher14 before: here I aim to emphasise the perception of competition coming from industry for academic research. Although only the smaller share of my respondents have talked about experiences with industrial partners and impacts from those collaborations, a strong industry-kind competitive notion permeates contemporary academic institutions generally, thus influences research practice and the construction of research identity in particular. The constantly adapting institutions of academia are in stronger correlation to the real world than academic researchers might perceive.

*Competing for Funding*

However, the accounts of my respondents provide insights into the consideration and emergence of strategic funding regimes that require collaboration, for example with industry, and account for the societal sector-spanning competition in knowledge production. Strategies of acquiring funding need to correspond to strategies of funding providers. Financial support is seldom provided for the sake of funding, but to contribute to institutional agendas of societal interests. The European Union, for example, produces and supports policies to generate and proliferate the knowledge society and economic growth as detailed in their Research Framework Programmes. The, now, seventh programme emphasises the 'knowledge triangle' of research, education and innovation (cf. The European Parliament and the Council, 2006:1), thus potentially spanning and transgressing all five sectors of knowledge production to position Europe as a major economic, political and social entity in the global setting. Non-governmental charity trusts support institutions that focus on the particular kind of research they have committed themselves to. Cancer Research UK or Marie Curie Cancer Care, for example, support research into understanding, preventing and treating cancer. Industry might provide funds for research and collaboration that will contribute to their technological field of expertise and production, for instance INTEL into nanotechnological research for the development of novel computer processing units. Public sector agencies, such as the UK's Research Councils, fund researchers and institutions in their respective fields with varying foci on disciplines and priority areas, often with the intention of fostering new ideas.

Despite the competitive dimension in both research presentation and production, or even because of it, academia and industry need to collaborate to benefit from aspects of either institution that the other does not specialise in. One might argue that academia provides basic science and education for young researchers, whilst industry has expertise in turning technologies into applications and commercialise these. At the same time, both need to communicate with governance agencies and the general public. Industry, which produces for users, stays in close contact with regulating agencies through lobbying for the process of producing (the work place) and for the process of using (the market). The contact to consumers is established through market research and advertising, which might lead to products that are more or less socially commensurable.

The positioning of academia within society and in reference to other sectors of knowledge production – here the focus has been on the industrial sector – requires academic scientists to broaden their spectrum of research practice, which my respondents have narrated as being either threatening or enriching; or both in some cases. The focus of academic research practices, however, still very much remains with the more traditional understanding of science, especially for those researchers who have moved from industry back to academia. Research liberty plays as much a role here as the ability to make a living from research.

Industry, as I have mentioned above, is a sector of knowledge production that academic scientists perceive as scientific. It's researchers are tolerated as somewhere between 'us' and 'them'. Academic and industrial scientists can relate to each other on scientific terms, although their institutional contexts and agendas differ. Their relationship seems more reciprocal than with groups perceived as 'non-scientific', such as social scientists and the public.

Nevertheless, a distinct demarcation between academic and non-academic (in this case industrial) knowledge production is narrated by my respondents. Academic research is research-interest led and as such 'pure' in contrast to societal-interest led industry. The notion of 'pure' science, however, represents an ideal and can hardly be understood as a defining part of contemporary science *practice*. This is reflected in academic science having to adopt aspects of non-academic approaches to research to be able to survive in the competitive funding regimes of contemporary science. The experiences and views of my respondents imply almost a necessity to collaborate with industry, as reflected in the rationales considered in the beginning of this section.

Because of the influences of societal interests in academic science practice as discussed above, it seems prudent to take a look at how scientists address non-scientific aspects of their research. This will also link to the perception that scientist have of the general public and the role of social scientists in regard to their scientific research.

## 4 Scientists on Non-scientific Aspects of Research

Perception, limitation and significance

I have previously referred to the 'non-scientific' when implying the wide range of social, ethical, legal, environmental, economic and so forth aspects of research and technologies (I subsume these under ELSA for now).

*Scientific versus Non-Scientific Knowledge*

ELSA could be described as playing a role encompassing all three stages of the research process: (1) the initialising stage by influencing the trajectories for research projects; (2) emerging in the production of knowledge; and (3) as a result from research and development in the application of knowledge and technology both within and outside the sphere of scientific research. However, scientists do not necessarily perceive ELSA as closely intertwined with their research. On the contrary, my respondents seem to display a certain disregard for the significance of non-scientific aspects in their own work, which might stem from a perceived separation of the process of knowledge production; the societal influences on it; and the implications of science for society. In fact, if researchers refer to these aspects, they tend to focus on the third stage of the research process. This implies a presumption that their research is based solely or predominantly on scientific and technical aspects, whilst other dimensions of their research will only emerge once the research is applied in society (outside science).

This contributes to the perception that academic scientists attempt to uphold a strict territorial claim. Certain ways of knowledge production and certain kinds of knowledge are negotiated as being 'knowledge' but not in the scientific sense. This might seem a simple methodological assertion, but I believe it to be also an epistemological claim in particular, and a social one in general. It reflects boundary work as 'turf-wars' on where 'real' knowledge is produced, thus my paraphrasing it as the 'non-scientific' from a scientist's standpoint. The connotation of 'real' here refers to knowledge that can be measured empirically, can be tested in reference to scientific theories and paradigms, or that can be reproduced, in short: of a scientific nature. Scientists seem to make a distinction for the evaluation of scientific work between the validity of scientific interpretation and the interpretation of scientific knowledge as informed by societal interests (for example in ELSA, but also generally by interest groups and by the public). The control over which interpretation should influence science governance and the perception of science and technology in society is contested. It is a question of which rules should be applied in the game of scientific endeavour. Scientists construct their identity in relation and delineation to what they perceive as 'non-scientific'.

*ELSA in Science Practice*

Narrated understandings of ELSA and their role in knowledge production processes imply that these aspects do not feature significantly in their perception, or at least are not at its forefront. Interestingly, one scientist, despite conducting research on nanotechnologies himself, has suggested that there is no clear framework for the social embeddedness of NST.

> **Researcher11**: “I think what there is is a lack of clear understanding, a lack of clarity what nanotechnology is going to offer society. I think that's never really been satisfactorily answered [...].”

Although the sentiment of the quotation and the practice of that researcher seem to contradict each other, I believe this to be connected to scientists' perception of the 'un-scientific' nature of speculations around effects from nanotechnologies. Many scientists seem to think that the public is obsessed with the utopian and dystopian of NST, but that there is no correlation between technology and more 'realistic' concerns (compare chapter 4). This suggests a vast communication rift between scientific and non-scientific actors as discussed in length in the case of GMO and in comparison to NST (for example Marris, 2001; Mehta, 2004; Pidgeon, 2004; Ryan, 2004; Sandler and Kay, 2006).

Some of my respondents portray science in practice as almost being disconnected from societal influences. On the other hand, a number of them have also expressed that 'non-scientific' aspects are implied in science and technology, and in their production.

> **Researcher15**: "[T]he whole point of science is that we don't know where we're going. You know, we're going in a direction, which, you know, even a visionary can't see. But if that's constrained, it's like to constrain any possibilities of being able to really address the global challenges of the now and the future."

The way the 'challenges' are presented here lends weight to the assumption that researchers may very well believe that the scientific needs to have priority over the non-scientific in order to fulfil its perceived tasks for society. And that the constructed academic and scientific 'us' should take up a higher priority than the perceived non-academic and socially infused 'them' in that regard. Researcher15, in particular, may feel very strongly about the role science plays for society, but this notion can be found in the accounts of many of my respondents. For example in Researcher22's conviction that everything should be done so that "technology can be used for as much good as possible". Or in Researcher24's belief in engaging with the public during the process of research for the benefit of rendering technology socially acceptable, or marketable.

The reference to the 'non-scientific' is often made without elaborating on its wider social quality. Indeed, the implied 'social good' does not seem to stand in relation to the 'socially acceptable' here; and it is reasonable to wonder if a scientist's perceived 'social good' is in fact the same as the public's 'socially acceptable'. It is interesting, however, to observe a certain learning effect. Most of my respondents, who make frequent use of communication platforms featuring discussions and presentations on 'non-scientific' aspects, say that the consideration of such aspects is of significance for at least the production of technologies and applications. This suggests that basic science is not affected by ELSA as it is still laboratory-embedded. In a conversation with a group of physicists after one of my interviews this sentiment was rather strongly proposed. This, then, leads to the question, or even challenge, in how far the narrated significance of ELSA for technology and application can be taken up or even internalised by scientists without a change in epistemology. The often simplistic reduction of the wide variety of ELSA to 'ethics' (by scientists) might be an indicator for how this challenge is probably answered today. These circumstances connect to the missing, or at least very limited, interaction between scientists and non-scientists.

> **Researcher23**: “I attended five to seven major conferences [...], which were mostly [attended by] nanoscientists or engineers dealing with micro- and nanotechnologies. Or [a European nanotechnology] forum, which was quite good and had speakers who talked on ethical aspects, as well. But from the other point of view, except the science and technology, there have been very few interactions.”

The lack of interactions here refers to the missing institutional drive in academia to establish procedures or platforms for scientists to engage with 'non-scientific' aspects of their research in a more integrated, coherent way. Apparently, it is mostly in European-funded and significantly crossdisciplinary projects that tentative engagement takes place. However, this perceived lack of engagement also finds its roots in the attitudes of scientists, as I have discussed above, as well as in the structure of science. The division of labour along the spectrum from content-generating to structure-perpetuating tasks (see chapter 4) and the epistemological background of scientists contribute to a strong focus on science apart from its societal issues. Another important factor here is, I argue, the notion of 'pure' science still prevalent in scientists' understanding of academic science.

The general and practical uptakes of 'non-scientific' aspects differ. While some researchers may believe that ELSA of their research or science in general should be considered and might be helpful towards the social acceptance of research and development, they might not commit to the task themselves. On the other hand, scientists might perceive the call for ELSA as a threat to research, and as a sign of distrust in science and themselves as scientists. In two or three cases during my interviews I noticed slight hostility towards the implications of my questions on current debates around nanotechnologies. Often, I thought that my respondents presuppose I intend to talk about debates on ‘grey goo’, or generally about ethical debates on the potential dangers of technologies. Some denied outright that there were any debates such as these, or downplayed their significance.

This connects to variations in the evaluation of ELSA. One of my respondents mentions that he has little time for “philosophical worrying” (Researcher2), while another consideres “the ethical stuff” in grant applications a (small) hurdle in the process of gaining funding (Researcher25). These are representations of two quite distinct ways of dealing with the ‘non-scientific’. The former refers to considerations of ELSA from within a societal context (the ‘philosophical’ here does not imply a scholarly approach), as opposed to scientific research, or as he put it, the “actual academic […] things”. The latter considers foremost ethical, economic and, possibly, social aspects from within the scientific context as part of the scientific process of proposal-writing and funding-application. Both are what might be called an *open engagement* as in each case the person considering the aspects does not attempt this from a social scientist or ethicist’s standpoint. In addition, they do not claim to be proficient in this process and do not actually engage with the matter meaningfully, that is they do not seem to aim for establishing ELSA scripts to include in their research. On the contrary, Researcher25's reference to the 'ethical stuff' implies certain strategies helping to deal with the ‘ethical’ or 'social' in applications, allowing for a swifter and acceptable (yet superficial) disquisition.

*ELSA in Scientists' Research Lives and Identity Construction*

The relationships scientists construct with ELSA in (and when) accepting the ‘non-scientific’ in the knowledge production reflect boundary work, which might be based on three interlinked premises: (1) considerations of time and workload, which I believe can be described as *practice boundary work*; (2) considerations of qualification and of labour division (*epistemic boundary work*); and (3) the construction of the scientific within ELSA (*adaptive boundary work*), regarding especially environmental and social aspects. The consideration and presentation of these three conceptualisations here connects very strongly with my reflections on the socio-technological worlds of researchers in chapter 4, and also draws on personal impressions from attending diverse NST events and speaking with researchers there. The first premise seems reflected in the accounts researchers have given on their daily work load as I have indicated in my thoughts on the *Division of Research Labour* in chapter 4. Many of my respondents have complained that they do not even have enough time for conducting their research. That entails that they do not find the time to engage with ELSA considerations during their working hours as a scientist.

> **Researcher2**: "But then later on, I'm afraid, we were more involved [with] the actual academic [...] things that we had to do, so we didn't have time for any philosophical worrying."

The priority of research for academic scientists is understandably the scientific, which, as I have pointed out above, they often construct as being unconnected from society as long as knowledge or technology production remain within the laboratory, or the academic sphere of research. In the quotation above, the 'academic' refers to activities taking place within the sphere of research in contrast to debates in the public domain of society. I do not think that, in essence, this implies that the respondent believes only natural science to be of an academic nature.

The first premise regards time restraints and work load. They are presented as one reason for neglecting ELSA considerations. However, this could also imply a strong division between scientific issues and ELSA in general. Nevertheless, my respondents' accounts provide reasons to believe that some very specific, science practice-focused ELSA are present in researchers' considerations. The input of social and economic considerations, to name but the most pervasive two, influence the trajectories of research as much as any technical and scientific issues, in fact even influence the latter two themselves. Several of my respondents remark upon issues of an economic nature affecting their research. The management of these is mainly done by choosing less expensive, or 'more cost-effective', materials or research infrastructure. Another approach is to cut corners in research by not pursuing all possible avenues of enquiry, thus by reacting in way of the methodology, which is evidently part of the research process. Even though scientists might be aware of aspects such as these impacting on their research, they do not seem to feel responsible for, and act further on, the comprehensive societal correlations that economic factors in research are embedded in. This approach to perceived non-scientific aspects can be tracked in reflections on cultural differences in

conducting research as well, among others. Cultural differences in science practice mentioned by at least three of my respondents regard research design and methodology.
The second premise emphasises the perception of epistemic differences between science and the public, but also between science and the social sciences and humanities. Considerations, which might be deemed significant debates among social scientists and ethicists, could be regarded as inappropriate or irrelevant for scientists and their research focus as they are not based on scientific 'facts' or physical 'laws' (the 'sufficient, impartial basis' for scientific research). It could also point towards what scientists aspire their research to be about, namely for the public good, but also for the good of science in the public eye.

> **Researcher17**: “I know lots of different bits to [the Drexler-Smalley exchange on nanomachines], but I have a very focused part of what I think […] relates to what's possible in the next few years, not really what is science fiction.”

Here, boundaries between what is scientific and what is social in knowledge production are constructed. Scientists enquire into the scientific and technical aspects, whereas social scientists and ethicists explore ethical, social and so forth aspects. And then preferably act as rapporteurs between science and the public. I have criticised this perception of the social sciences as doing 'public relations work' for science in the previous section, which might also imply a hierarchy between the different academic disciplines (at least in regard to technological applications) that cannot be justified, but constitute disciplinary defence mechanisms towards a legitimation of academic science as space for knowledge production. At the same time, this boundary work can be critically interpreted as being technology-deterministic.

> **Researcher11**: “I think these are very specific aspects of nanotechnology. And I think that a lot of these would relate to people's perceptions of how they might be used. In my area, I don't think there is such a big problem. […] But that's not really my area of interest or expertise. So, I don't really follow the broader debates. I leave that to other people.”

Such representation of difference is taken to a practical solution, again, in the division of labour between the different academic disciplines, or between the different institutional agendas that might exist among project partners. I also refer to institutions because some partners of academic scientists in larger projects, especially international ones, are not necessarily affiliated with academic institutions. These might be researchers from the public sector, such as industry, trusts, state research organisations, or non-governmental organisations. Then again, the separation of research tasks is not automatically clearly defined according to institution. However, their agendas seem to influence the thrust of research, its conduct and presentation, and as such they influence institutional scripts.

At the same time, funding bodies increasingly expect applied science projects, particularly of technology transfer, to include researchers from areas of research focussing on the social and the ethical, especially in the nano- and biotechnologies as novel and technoscientific research fields.

The third premise connects to the perceptions of what is scientifically relevant and of ELSA as *resulting* from knowledge and technology production. When scientists, on their own accord, show genuine concern about societal effects of NST research, their concerns often focus on scientifically graspable aspects of science and technology. These are aspects that can be quantified and tested, and that correlate to existing scientific notions, the above mentioned scientific 'facts' and physical 'laws'.

> **Researcher14**: “I can see nano-particles released into the environment now, it's happening all the time, and maybe that's what we should be putting our efforts into. [...] It's just when you go for funding, you don't always get the funding to check on the toxicology of those things.”

> **Researcher24**: “[I]t's becoming increasingly recognised that there needs to be more studies to know truly whether there are any actual negative effects on health of nanoparticles. [...] But the concern seems to be that naturally occurring nanoparticles are a very wide distribution of sizes and scales and things. And the manufactured ones are going to be in much higher concentrations and much more regular and that nobody really knows what kind of effect this is gonna have.”

Considerations of the toxicology and related aspects of NST are not uncontested within the sphere of research itself, but they feature often in scientists' accounts on potential issues for society. They do so in a different measure than what seems to be foremost in the publics' mind (cf. Scheufele *et al*, 2007). Also regarding the attitude towards public concerns, the difference in perception is still adhered to.

> **Researcher23**: "That's a bit of reading from the technology point of view, but not really the public perception […]."

The adaptive approach towards ELSA (in the case of toxicology this would refer to environmental and health aspects) is brought in conjunction with the societal context. It can thus be seen as a tentative exposure to and handling of non-technical aspects of technology. The concerns on effects do, however, remain within the framework of science. Therefore, the influence of public concerns about research seems to be limited in effect on scientists' research practice. In addition, the interaction with social scientists and ethicists working on the same project or looking at science and technology usually remains very sparse. The latter's work is presented by scientists as an outsider's perspective and often seen as a public relations job for technologies emerging.

A cause for scientists to believe that generally, however, ELSA do not affect their research practice much can also lie in the 'scientification' of these aspects in the context of social science enquiry. In a personal talk with a group of physicists, for example, I tried to dissolve the abstractness of ELSA by pointing out what I perceive as every day issues for research: safety at the workplace; decisions for, acquisition and disposal of materials; choice of research ideas and how to pursue these etcetera. Most of the physicists then acknowledged that these are in fact aspects of research they need to deal with on a regular basis. The diffuseness of declaring these aspects as part of ELSA, I believe, might stem from being perceived as inherent to research and as such not 'ELSA'. Although this makes a case for the reciprocal influences of societal and technical aspects, it would at the same time render it much more difficult for scientists to consider these aspects outside their scientific focus as societal concerns.

In summary, the scientists' research practice seems considerably affected by 'non-scientific' considerations. These aspects might be translated into ELSA only later on, but they become part of scientists' *practice* and *strategy* dimensions in their identity construction. The 'non-scientific' aspects are also significant for the potential of collaboration, and for its conduct. My data suggest that scientists feel the need to respond to views on science from outside the sphere of research as diverse mechanisms of establishing legitimation and accountability take effect, not least in funding processes. Academic research is influenced by efficiency and productivity issues as well as by expectations of creating socially robust technologies and knowledge to be applied in society. This is reflected in science and economic policies. Academic science is embedded in such societal considerations, which scientists might refer to as indirect benefactors of their research. The UK government, for example, provides conceptual frameworks such as 'Knowledge Economy' (in 1998) and 'Innovation Nation' (Department for Innovation, Universities and Skills, 2008). Simultaneously, concerns over generating employment, commercial growth, and economic diversification impact on academic science and its practices. The institutional role allocation proposed towards an 'Innovation Nation' is telling. The Department for Innovation, Universities and Skills (DIUS), the Department for Business Enterprise and Regulatory Reform (BERR) and the Business Council for Britain are called to regulate the promotion of innovation, thus clearly outlining the political congruency of the scientifically active sectors of society, the business/commercial sector and the public governmental sector.

The three premises of how boundary work is constituted towards 'non-scientific' aspects of scientific research are based on academic science structure. It influences attitudes and outlooks of scientists in regard to ELSA. At the same time, science structure is subject to science governance and as such science policy, which considers 'non-scientific' aspects for research conduct and technology transfer. It can be argued, then, that science practice is permeated by considerations of these aspects of research. Crossdisciplinary collaboration, scientifically required but also expanding the potential of technology transfer, seems to foster this stronger inclusion especially in NST. Again, for NST the macro-economic aspect plays a strong role in its legitimation, particularly the funding aspect of it.

I have mentioned funding several times in my analysis. I believe that funding, especially in the context of accountability of research and its spending, is a major driver for academic scientists to consciously regard what they perceive as 'non-scientific' (or 'non-technical') aspects of science and in knowledge production. Therefore, in the last section of this chapter I take a brief look at the case of funding strategies in science as a reaction to requirements from outside the sphere of research.

## 5 Example: Academic Scientists' Funding Strategies

Societal influences on funding applications and research outlooks

As identified before, the notion of legitimising research (resulting in mechanisms of accountability) has become a significant aspect of scientists' research lives. Strategies of acquiring funding have become part of their outwards-orientated (communicated) identification processes that reflect on research practice. This communication to actors outside the sphere of research is an aspect of research collaboration in the wider sense. I examine this aspect here to provide an example of the relationship between academia and other places of knowledge production, but also of wider collaboration in the field of NST. This example connects to the general outline of interaction between scientists and the sphere of governance I have developed before.

Scientists' communication with the sphere of governance, cutting across the sphere of research and the public domain (Wienroth, forthcoming), has impact on how scientists frame their research, and how it is conducted, at least administratively. Reactions to NST lobbying, as I described in the section on *NST and Research Identity* in chapter 4, are among the influences from the sphere of governance. Here, negotiating the nature and potential of NST has produced impacts on identity construction.

My data shows that funding is perceived as a driver for research, but more importantly it is central to the possibility of doing research at all. Considering technical requirement, but also the institutional structures of science in different societal sectors, availability of funding is the key to contemporary knowledge production. Researchers have reacted to this ubiquitous matter by employing a societal element, science and economic policies, and represent their research as 'nano-research' in funding application if deemed opportune. The societal element is illustrated by the influence that demands, incentives or expectations from research governance institutions have on the way research is portrayed. An instrumental type of framing often takes place on open communication platforms such as conferences or more institutionalised networks. Research organisations affiliate to 'nano' in name or agenda, or in project applications. Through such tactics researchers' identity-dimensions of *practice* and *strategy* are influenced. As Researcher15 recalls, the research agenda of the institute he works for has changed to a focus on NST in reaction to funding schemes of organisations from the public sector.

> **Researcher15**: “To some extent [re-labelling research institutes] is politics. [...] [The regional development agency], when it funded what was then called the Regional Nanotechnology Initiative, had a number of funding sources. And one of those was DTI [Department of Trade and Industry] money. [...] And the other funding stream was the ERDF [European Regional Development Fund].”

His research practice has been changed by expectations from the outside and the reaction of his institutional framework to these. Resistance to such a process shows in the researcher's reference to the labelling-process as a political move, however in other quotations he accepts the changed outlook of the institute. Science policy here features aspects of governmental economy policy in the aspect of wealth generation via regional development. Science, then, underlies competitive forces not just on the micro-scale (among science), but on a macro-scale in economic and general societal competition. Indeed, the concepts of 'knowledge economy' and 'knowledge society' ('Innovation Nation'), promoted by governmental science policy (cf. Department for Innovation, Universities and Skills, 1998, 2008), emphasise the competitive and economic nature of science. The combination is particularly strong in academia, where education and research contribute to both concepts.

> **Researcher24**: “[I]t addresses what's seen as a priority need to keep up with what's going on in other markets and states [...].”

This is a part of ELSA that seems more present in scientists’ minds, particularly when engaged with managerial tasks. It might reflect their understanding of contributing to society on different levels.

As I mentioned before, business considerations permeate research institutions (cf. Martin *et* *al*, 2004; Webster, 1994), particularly in regard to new and emergent research fields such as NST. Funding can come from many different sources and present a driver for a change of focus, or at least for a change of framing research. Universities have reacted to funding opportunities by creating new research spaces (see also Johansson, 2003). These spaces are usually only new in name and agenda since distinctively novel academic institutions remain rare. The newly framed or established organisations can be understood as utilising existing scientific resources and structures, and to create new scientific capital, but also social capital, for example in form of prestige. These forms of capital, again, directly contribute to the researchers' identities.

> **Researcher8**: “Obviously [the institute] was born, if you like, during a period where nanotechnology was the key word in fund-raising. And so, anything that could be loosely associated with that word was sort of jumped upon as being a good idea and should be used as some evidence of nanotechnology taking place [here].”

Whereas the first half of the quotation focuses on the functional aspects of nano-labelling, the second half refers to prestige as social. The mentioning of the utility of 'evidence' for NST-research taking place at the university implies the attribution of value to the mere existence of nano-research. This, I argue, connects to the notion of ‘progress’ that is still deeply entrenched within the understanding of science both within and outside the sphere of research. Through self-reference to ‘progress’ the perception of researchers in society is reflected. Innovation seems to be the slightly less deterministic terming for progress, and is strongly connected to the idea of doing business with knowledge ('knowledge economy'), of considering economic aspects in science more closely. Here, again, we see that the separation and highlighting of academia as the space of 'neutral' knowledge production in contrast to other societal sectors cannot be retained. Academic scientists' notion of a 'pure' science might then be an element of legitimising academia as a distinct space of research. The need may arise in reaction to increasing governance mechanisms (cf. Rip, 2005) such as ethical considerations in science application processes and accountability procedures for research ideas, their pursuit in methodologies and research choices and spending.

## 6 Summary

In the overall approach of my analysis of NST science practice and disciplinarity, this chapter has explored aspects connecting collaboration and research identity within academia with the societal context. Owing to the understanding of NST as being mainly a field of applied research and technology development, I have examined scientists' construction of science practice in regard to 'non-academic' and 'non-scientific' elements in their research. Foci have been on collaboration with industry and on the negotiation of ELSA in scientific research, in particular economic aspects as these connect to vital funding strategies in NST, which I identified before. Furthermore, in this chapter I have critically explored the notion of 'pure' science as a means of legitimising and demarcating academic science.

Scientists seem to sustain the idea of a 'pure' science and set themselves apart either in motivation and/or production processes from other spaces of knowledge production. However, *applied science* is entangled in manifold societal interests (commercial, safety, environmental, economico-political and so forth). These come to bear on academic research through science policy and scientists' personal perceptions of science's contribution to society, but also in collaboration with non-academic societal sectors of knowledge production, such as industry. Scientists' strong focus on scientific aspects as knowledge basis influences the communication potential between academic scientists and non-academic or non-scientific actors. This potential is limited in extent and in intent, in particular as my respondents demarcate the group of academic scientists in contrast to other groups. The 'us' is narrated along the notion of 'pure' science ('neutral' knowledge produced on scientific merit without societal interests). Non-academic scientists, academic social scientists, or the public, which is perceived as being neither academic or scientific, are constructed as 'them', that is as actors with a very strong societal influence on their approach to knowledge.

Nevertheless, my respondents feel that industry has become a frequent partner in knowledge and technology production. Some acknowledge a strong impact on the way research is managed and conducted. However, framing industrial research methods are portrayed as decidedly non-academic in that there seems to be (1) only limited feedback from industrial researchers to their academic partners and (2) the focus of industry is necessarily commercial with aiming for products and the marketability of technologies. Simultaneously, industrial scientists are recognised as adhering to 'scientific' rules. A constant personnel exchange takes places between academia and industry through education and career decisions, also supported by the increased focus on applicable research in academic science. In addition, scientists who had been working in industry before moving (back) to academia seem to adopt academic scripts of conduct without difficulty. The perception of industrial research might be understood as non-academic, but it is still scientific and as such closely affiliated with the 'us', expressed through scientific collaboration.

The 'non-scientific', on the other hand, is more sceptically constructed as aspects outside the responsibility, or at least competency, of scientific research. Scientists apparently perceive these as means to conform to science policy and gain access to funding. The way scientists refer to ELSA signifies boundary work and reflects on the construction of research identity in a sharp contrasting between what is perceived as a genuine scientific task and aspects that are not quantifiable, but of a social, or societal, nature. A case in point are scientists' considerations of the toxicology of nano-particles, which essentially refers to environmental and health related aspects of these technologies, but through this also to social and ethical aspects. Nevertheless, the latter aspects are not explicitly discussed. A notion of tension seems to exist between scientific research and its embeddedness in society. Although there is a tendency towards recognising ELSA and public concerns among my respondents, the contrast between what they understand as scientific and appropriate to engage with and the 'non-scientific' is highly emphasised.

In the following chapter, I review my analysis in the context of the ongoing debate around NST and the change of science by relating the different themes and findings of my analysis and then evaluate their contribution merit.

# Chapter 7: Research Practice and Disciplinarity in NST



## 1 Introduction

This chapter provides an overview and summary of my analysis. I draw out my original claims and consider the implications NST can have on academic science in general. Also, I address questions prompted by my analysis for further enquiry.

In my analysis I have explored scientists' perspective on NST from a sociological point of view. I have established an understanding of how researchers construct their research, or disciplinary, identity in regard to NST (see chapter 4). Interconnected with this, I have examined how research collaboration of varying disciplinary natures changes academic science practice (see chapters 5 and 6). I have also explored the input and impact of some non-academic and non-scientific partners and aspects in NST research.

The ongoing debate in the humanities and social sciences about the nature of nanoscale research has influenced my starting point and outlook onto the sphere of research – and also the sphere of research governance – in academia. However, my respondents' views on NST have provided the means for me to expand the understanding of how new and emergent sciences and technologies – NST being one field of these – feature in and impact on research practice in academia. This approach is of particular interest in the context of the 'knowledge society' and 'knowledge economy' as I pointed out in chapter 6. These two concepts define the governance approach to knowledge production in society. As academia is embedded in societal interests, these approaches impact on academic science practice and its regulation. This impact is reflected in its changing disciplinarity.

Therefore, the methodological strategy for my research has been to focus on the practice-orientated perspective of academic scientists. My main research question focuses on that element: what is the nature of academic research practice in NST? Collaboration and its disciplinarity, in particular, have been of interest to me due to the novel and emergent nature of this crossdisciplinary research field. However, the focus of my question widened over the course of my literature review. The debate around the co-production of knowledge between academia and the public sectors has become a significant context for my research question, in particular for scientists' identity negotiation towards NST and with non-academic and non-scientific aspects in science practice. Aspects originating from day-to-day research, such as identification processes and collaboration, are influenced by debates of research governance. In turn, science practice influences governance, for example in regard to new and emergent research fields, such as NST (see funding strategies discussed in chapters 5 and 6).

I have used the case of NST because of its wide discussion in the sciences and the social sciences. Institutions of NST have emerged, but the field's institutionalisation is not yet consolidated. In addition, the understandings of concepts of NST remain relatively open, varied and even contradictory. A number of subsidiary questions arose from my literature review and were then explored through my fieldwork and its subsequent analysis; these include:

- How do scientists working at the nanoscale perceive NST?
- What role does NST play in scientists' construction of their research identities?
- Does disciplinarity still feature in the construction of research identity? If so, how?
- Is NST becoming a discipline in its own right?
- What role does collaboration play for research in the field of NST?
- What kinds of disciplinarity feature in NST-collaboration?
- What is the extent of collaboration with non-academic or non-scientific partners?
- How do scientists negotiate non-scientific or societal aspects in their research?

Using these questions, in the previous three chapters I have provided in-depth analyses of the main elements of my research question: disciplinarity in research identity in chapter 4; disciplinarity in collaboration in chapter 5; and the negotiation of non-academic partners and non-scientific aspects of research in chapter 6. In this chapter I combine my findings in reference to the main points of the debate on NST in the literature, and in reference to the theoretical framework for my analysis, which I introduced and argued in chapter 2.

In the first section of this chapter I present a brief overview of the findings from my analysis. I draw out the linkages between these and present a coherent picture of how scientists negotiate their disciplinary background and research experiences with NST research practice and its requirements.

In the second section, I evaluate my analysis in relation to ongoing debates in the Sociology of Science and Technology (disciplinarity and research identity) and Science and Technology Studies (in regard to Mode 2 knowledge production reflected in researchers' accounts on collaboration and non-scientific aspects of their research). I reflect on main issues raised in my research, examine aspects of my analysis that challenge or support ongoing debates, and I identify some of the implications of my research findings.

In the third section, I consider first and second order disciplinarities as an outcome of my analysis of disciplinarity in research practice. I aim to provide (1) an overview of the three types of disciplinarity most commonly used, and (2) a basis for understanding what kinds of disciplinarity feature in NST by elaborating and discussing the axioms of these. This I believe to be pertinent because NST is considered and expected to be interdisciplinary (for example Arnall, 2003; Siegel *et al*, 1999; Wood *et al*, 2003) and has been referred to as being multidisciplinary (European Science Foundation, 2005:10; Schummer, 2004:448). At the same time, the focus on application in nanoscale research suggests a transdisciplinary element as conceptualised by Nowotny (2003).

In the fourth section I consider wider questions raised by my findings, thus indicating future trajectories for further research into NST, and into science practice and its relation to society. The questions discussed there lead towards on overarching question that provides a context for the wider questions raised.

The last section of this chapter embeds NST in the context of academia and science. The focus here is on examining the degree of generalisability for NST, and on exploring the role the field plays in the co-evolution of science and society.

## 2 NST and Academia – Analysis Reviewed

Connecting disciplinarity, research identity, collaboration and the knowledge society

My analysis follows three main themes, exploring structural and practical aspects of NST as a new and emergent field of science and technology: (1) how do researchers construct their identity in regard to NST, (2) what role does disciplinarity play in research identity and practice, and (3) how does collaboration feature in scientists' accounts of research identity and practice. These themes of identity, disciplinarity and collaboration, when brought together, help to construct an understanding of contemporary academic science both in regard to research practice and in relation to society.

The three dimensions of identity construction are expressed through belonging (disciplinary structure), practice (actual research and distinguishing specialisations) and strategy (potential research), an understanding I have established in chapter 4. I argue that these are reflected in the narratives that scientists construct in regard to their research backgrounds and interests (chapter 4), in their understanding of collaboration with other researchers (chapter 5), and in their perception of science's place in society through non-academic and non-scientific aspects of research (chapter 6). Research practice, then, is influenced by research, or disciplinary, identity. And this identity is adapted according to research practice.

*Disciplinary Identity*

I have explored and structured scientists' accounts of their research practices with regard to nanoscale research in the wider sense, but also in regard to their positioning towards the field of NST as a narrated entity. In my analysis it has become apparent that the way scientists construct research practice in NST can be understood along the lines of disciplinary positioning (the belonging dimension of identity) as well as disciplinary practice (the distinguishing and potential dimensions of identity). Both are reflected in accounts of research interests and of experiences in collaborations. Negotiating disciplinary positioning and actual practice is part of overarching boundary work, which emerges as alternating between rejecting and utilising notions of NST (compare with Burchell, 2007). As this field has vague boundaries and presents many diverse understandings both scientifically and societally, this alternating can be seen as constant renegotiation that produces tension for the scientist, but also for the field's institutionalisation. Requirements and expectations of research governance in contemporary science funding regimes add a strong element to this boundary work. The tension, then, is expressed by necessitating scientists to find ways to legitimise their research through research identity (science as profession) and practice (research as 'progress').

The discipline-orientated boundary work within the sphere of research is challenged by the means of interaction in research practice. Different platforms of exchange seem to allow different aspects of research identity and practice to come to the fore. Platforms of closed exchange emerge from a discipline-structured framework. In the case of NST, specific nanotechnological periodicals have started out catering for specific audiences. Some focus on physicists or material scientists, and others on the various chemical or engineering subdisciplines (Schummer, 2004b:461). These platforms, however, provide a disciplinary home for information, publishing and affiliation, adhering to specific disciplinary scripts and thus addressing structural aspects of research identity. However, interdisciplinary cross-over takes place, and increasingly so. Researchers incorporate aspects in their work that overlap or even span diverse disciplines such as physics, material science, chemistry or biology, particularly at the borders of these disciplines. The blurring of boundaries becomes apparent here as the research problem increases in significance and researchers need to utilise more than their disciplinary repertoire of approaches, methods and tools. Research collaboration and research interests foster the crossing of disciplinary boundaries and seem increasingly presented also on closed platforms. The practice aspect of identity comes to the fore even when collaborators of different backgrounds present their research on different platforms. NST research is usually based on collaboration, and results are influenced in too many ways to present a project or its results as single discipline-based, even if research is presented in a discipline-focussed way.

*Boundary Work in Crossdisciplinary Collaboration*

Crossdisciplinary collaboration has become a regular research method in science and for scientists, expanding and simultaneously regimenting research practice. Collaboration, however, mainly takes place on dedicated platforms of exchange and coordinating project meetings, not so much 'at the lab bench'. Therefore, the communication of ideas, research work and results takes on a very significant role in crossdisciplinary collaboration. Collaboration emerges as a necessity owing to the increasing complexity of research problems, the growing costs of instruments and tools, and science-external and science-internal scripts. The following are three examples of the array of expectations, requirements and mechanisms that constitute contemporary science regimes and relate to collaboration and crossdisciplinarity.

(1) Science produces knowledge and technology that tends to be described as 'innovative' by scientists, particularly by managerial scientists. Innovation is a term widely used in society to promote new knowledge. It is also compatible or even convergent with the notion of 'progress' that scientists tend to incorporate in legitimising their research. Thus, scientific research is driven not simply by science, scientists and practitioners, but also by governmental and commercial interests (cf. Webster, 2007a:49). Societal interests are implied in notions of progress and innovation through the application of scientific knowledge in the public sphere.

(2) From the accounts of my respondents it becomes apparent that science governance and

funding bodies increasingly require scientists to conduct 'interdisciplinary' research (see sections 2 and 3 of chapter 5, and section 5 of chapter 6). This 'interdisciplinarity' usually implies that contribution to knowledge production shall be done through collaboration across disciplines. Also, an expectation of 'interdisciplinarity' can refer to the specialisations that researchers themselves develop. However, the concept of interdisciplinarity seems to remain mainly diffuse as collaboration 'side-by-side' (multidisciplinary) features more often than truly synergistic (interdisciplinary) collaboration (cf. Schummer, 2004a, 2004b).

(3) A structural mechanism of the science regime is academic career-building upon track records, esteem factors, personal specialisations and research interests. Track records and esteem factors are often related to discipline-orientated institutions. At the same time, research interests and specialisations, influencing one another, emerge and re-emerge from research and contribute to the track record. Both are also guided by the access to funding that science governance grants. In the first five sections of chapter 4, and in section 3 of chapter 5, I discussed these issues in length. It can be argued that in NST (a) the notions of innovation or progress and (b) track record building come together in crossdisciplinary and collaborative research practice.

In the setting-up and contextualising of crossdisciplinary collaboration, platforms of open exchange feature regularly. Indeed, the transgression of disciplinary boundaries in research practice becomes more evident in the case of open platforms. Here, the focus is on complex research problems, or on the advancement of a part, or the whole field, of research. Researchers from different disciplines look for expertise and develop projects with clear expectations towards crossdisciplinary collaboration. However, the difficulties here lie in the different epistemic cultures of the participants as much as in their personalities. Structural issues generated by the remaining disciplinary and administrative divisions in academia create issues for crossdisciplinary collaboration, as well. At the same time, open platforms of exchange encompass collaborations with non-academic partners. They render the strict demarcation of knowledge production structurally difficult, both in regard to scientific disciplines and in regard to different spaces and agencies of knowledge production.

The identification, or boundary work illustrated by my respondents appears reflexive and defensive in light of their overall research practice. Whereas the belonging dimension of identity plays only a minor role for actual research activity, it does take on a strong notion in the representation and negotiation of that said research. Especially in collaboration, this dimension provides an established framework with scripts and institutions to rely and fall back on, the professional context to locate and position personal research activity. It also helps to understand what a research partner brings to the project, as I discussed in section 4 of chapter 5. In that regard, my respondents refer to disciplines and specific expertise when describing their collaborators. For collaboration in NST, one's own disciplinary background (belonging dimension) is as significant as being able to distinguish oneself (practice dimension) from disciplinary or project colleagues. This distinction can lie in one's individual research specialisation, or the ability to bridge specific disciplines or fields of enquiry.

*Negotiating the Non-Scientific in Academic Science*

My data suggests that efforts to distinguishing science and scientific research from other kinds of knowledge production in society has become similarly significant as the discipline-orientated distinction. The legitimacy of both academia and the disciplinary structure of science seem perceived as threatened when respondents discuss the narration of NST in public and governance domains (see sections 6, 7 and 8 of chapter 4). Influx of societal interests to scientific research and of non-scientific scripts in the evaluation of scientific knowledge are probably the main elements of concern here. Indeed, accountability for research aims and research spending might have become an existential accountability, a matter of 'to be or not to be' for academic science practice. Competing public agencies of knowledge production (the five sectors mentioned in chapter 6) seem to be seen as potentially contesting academia's specific role in the production of scientific knowledge. That becomes particularly apparent for institution-transgressing research within discipline-overlapping and discipline-permeating fields such as NST. This field is co-constructed by different societal sectors, and the normative power over new and emergent science and technology fields does not lie with academia alone (any more).

NST is one example in the development that has expanded and accelerated with the call for and support of research into non-scientific aspects of scientific research, as described in section 4 of chapter 6. In biotechnologies, information technologies and other fields of applied science, or technoscience, these ELSA efforts have emerged. Indeed, the increasingly expected involvement of ELSA might result in the emergence of what could be called *socio-technoscience*, emphasising the co-evolutionary societal impact on technology production through involvement of the social sciences, humanities and 'public engagement'. This connects and embeds technoscience in science-accountability mechanisms and thus science policy, reminiscent of Webster's “Social Science in the Policy Room” (2007b).

In their boundary work, however, scientists seem to sustain an ideal of 'pure' science, a science not entangled in societal interests but based solely on scientific scripts (methods, tools, epistemology) and interest in knowledge *per se* (see section 3 of chapter 6). This notion can be understood as an attempt to clearly demarcate academic science from other approaches to knowledge production, conjuring the loftiness and impregnability of the 'Ivory Tower'. Nevertheless, research practice challenges this view, as I presented in sections 4 and 5 of chapter 6. The conduct of applied science, such as NST, within academia and in collaboration with non-academic partners seems to contradict the notion of 'pure' science on a very apparent level. However, some of my respondents negotiate applied science and collaboration with industry as a necessity to gain funding and access to scientific infrastructure that is not easily available in academia. This is done to further scientific knowledge production. However, further challenges to 'pure' science are embedded within researchers' expectations in regard to the social utility of their research. These are expressed, for example, in patenting and licensing processes, but also in esteem building and career choices, and in describing science as producing knowledge for the 'good' of society.

Contributing to this line of argument, scientists' anticipation of public views of their profession and their work might be seen as one example of societal impact (see for example Scheufele *et al*, 2007). This might be institutionalised in science policy and accountability mechanisms. These can draw from non-scientific research on ELSA, that is on ethical, environmental, economic, legal, social and so forth aspects (see for example the recommendations of The Royal Society *et al*, 2004; or those of the Department of Trade and Industry, 2005). Researchers' boundary work is thus influenced by the relationship of science to society. Science, and academia as a culture of science, are presented as producing knowledge for society as discussed in section 4 of chapter 6. Scientists consider potential risks or benefits of that knowledge (and technology) and thus connect to societal expectations. They do so from a scientific point of view, transforming some ELSA considerations into scientifically approachable issues, as in the case of toxicity of nanomaterials, or the lack of production standards of these. Nevertheless, it appears as if scientists sometimes go as far as to ascribe an 'ascientific' nature to the public's view on scientific work.

## 3 NST and the Knowledge Society – Analysis Evaluated

Main analytical issues, challenges to and support for debates in the existing literature

In the previous section I presented a brief overview of my analysis and the interconnectivity of my findings, thus providing a preliminary account of the implications of my research. In this section I evaluate and distinguish the main issues that have emerged in my analysis, and reflect on the challenges or support they may provide for the issues raised in the literature and the theoretical framework discussed in chapter 2. These are issues of contemporary knowledge and technology production in relation to issues around NST as a case in point.

My review of the social scientific debates around the nature of science in contemporary society, along the example of Nanoscale Science and Technology, informed my choice of themes through which to explore the nature of science practice in contemporary academia. One of the main ideas has been the perception and description of increasingly blurred boundaries in the production of knowledge and technology. These include boundaries between disciplines, between different spaces of knowledge production, and between science and technology. The blurring and the diffusion of different expertise and epistemology are implied or described in terms such as 'Mode 2', 'co-evolution', 'co-construction', 'technoscience', 'hybridisation', 'inter- and transdisciplinarity', among others. The analysis of this blurring constitutes a major renegotiation in the social construction of science and technology. The disciplinary nature of science seems at least challenged, if not in structure then at least in research practice, and the concept of 'collaboration' acquires an additional dimension.

But what is new? To begin with, the main thrust of my findings corresponds with the general interpretation of contemporary knowledge and technology production as being co-constructed by science and society. Or, to be more precise, by scientific and non-scientific aspects in science practice. However, the details of my analysis provide a more faceted understanding of science practice. They help to explore the nature of NST (as a new and emergent science and technology) within the context of academic knowledge and technology production along the lines of identity and collaboration in the context of disciplinary modulation. Therefore, my analysis spans a range of *interdependent* aspects of research. It attempts to combine a normative structural perspective, the disciplinary structure of knowledge production, with a practical perspective of the scientific profession, that is identity construction in research practice.

I propose that NST is an example of crossdisciplinary, collaborative and applied science practice that emerges in many areas of academia. It features distinct elements that help to understand crossdisciplinary research and that go beyond the explanatory model of 'Mode 2'. I elaborate and summarise my analysis here.

*NST as a Dichotomous Entity*

NST as an entity, to be sure, is *dichotomous*. It has been stylised very much from the outside of the laboratory in that the term 'nanotechnology' has been taken up by science policy from early on. Expectations and promises as well as concerns have rendered NST a societal entity, possibly even alienated the idea of NST from scientists as 'un-scientific'. This view is strongly reflected in the accounts of my respondents and begs the question as to whether there is any research taking place that can be categorised as NST. And here, I contend, does the dichotomous nature of NST come into full play. There are two distinct understandings of NST: (1) societal interests and science policy, and (2) technical capabilities and science. Both are connected through funding mechanisms and science governance attempting to render scientific knowledge (production) more socially robust. They are also connected through scientists' own interests in researching 'for society'. Researchers have utilised the terms of NST from early on in response to science policy, but also because much of the field's key terminology is part of existing disciplinary expertise. Nanotechnological research does take place, however apart, yet influenced by, nanotechnology representation.

These, then, are the three major strands of my main conclusions: (1) NST as socio-technoscience, (2) NST as a disciplinary macro-structure, and (3) NST as a practice-constructed research field relying on disciplinary diversity.

*NST as Socio-Technoscience*

As I pointed out previously, there are not only many conceptual understandings regarding the nature of nanoscale research, there are also many different terms describing it. In most cases, researchers will simply refer to 'nanotechnology' when talking about the field, as technology production lies at the heart of it. And in some ways, this reduction does seem plausible, as research at the nanoscale draws on the knowledge and skills from many established sciences. Nanoscience *per se* does not exist, certainly not as a widely recognised discipline. Judging by many scientists' estimation, it does not exist as a coherent structure constituted of all knowledge production towards the exploration and manipulation of atoms and molecules either. However, technology is based on scientific expertise, and here the idea of *applied science* seems to be a rather appropriate concept for NST. Applied science here encompasses basic research from contributing sciences to the development of (nanotechnological) technologies and applications (Mehta, 2002:270f).

This connects to the evaluation of contemporary research as becoming a hybrid entity. The combination of terms in 'Nanoscale Science and Technology' and 'new and emergent science and technology' already imply this transgression of practice, expertise and agenda between science and technology, but also between academia and other sectors of society. Borders between scientific knowledge production and its application in technology production, and between academia and industry for example, have become not only diffuse but rather difficult to observe in NST. The same scientists who conduct research in fields such as physical chemistry, molecular biology, quantum physics (but not necessarily identifying with these fields as disciplinary background but viewing these as contributing to their research) work on developing various technologies. These range from engineering nano- or micro-particles for specific chemical and physical reaction processes to creating structures such as carbon nanotubes, and to working on clinical applications such as cancer diagnostics based on nano-scaled bio-markers.

The main point here is that many researchers are aware of the overlapping research they do in NST, acknowledge it, but at the same time identify personally with established disciplinary structures. Their research, however, often does not fit into a clear-cut discipline or even sub-discipline. The clinical scientists and physicists of my case study show less difficulty in 'pinpointing' their research than other researchers. Clinical scientists often describe their work in regard to the medical or clinical application of their research, whilst physicists seem to have a particularly strong affiliation with their disciplinary background in general. However, most of my respondents found it difficult to describe their research in disciplinary terms. Generally, this difficulty seems connected to the necessity to specialise and develop a unique portfolio of wide-ranging expertise to contribute new research ideas to the scientific endeavour. Simultaneously, scientists need to gain merits and esteem in the ongoing disciplinary structure of academic science. There is no contradiction in the idea of a specialisation on wide-ranging expertise. Complex problems, which form the foundation of research in NST, require knowledge and skills from sub-disciplines that may not be confined to one disciplinary pillar. Physicists (by training) may draw on chemical expertise and apply engineering skills whilst still identifying with physics as their disciplinary background. However, they do not necessarily describe their research as physics. This is what I have tried to draw out by dividing disciplinary identity into the three dimensions of structure, practice and strategy. NST as a research field does not provide a strong or established structural background. A reason is that nanoscale research relies on, and is seen as originating from, areas within established disciplines.

In summary, the technoscientific nature of NST is reflected in several aspects. (1) The problem-focus in NST is apparent, however the scientific research at the nanoscale is not framed as nanoscience but as a specialisation of another discipline (for example nanomagnetism as an aspect of physics or its sub-field of magnetism). Therefore, (2) the application-focus is dominant. Researchers' own interests, and societal expectations, requirements and incentives affect scientific agenda-setting through accountability-mechanisms. These mechanisms are based on policy decisions regarding what is being researched and funded. Also, (3) NST is portrayed by most researchers as a process of incremental development of science and technology towards the very small scale of matter. This is done to understand and manipulate the material world, which leads to the merging of science and technology in NST.

Even more so, NST is a *socio-technoscience*. This concept connects to Jotterand's 'integrated model' (2006:663) of societal and political aspects and its implications for academic 'pure' science as becoming obsolete in what Ziman calls 'post-academic' science (*ibid.*; Moriarty, 2008). However, the notion of a socio-technoscience goes beyond the integration of ELSA in the research process. The influx of accountability processes as well as ELSA and various kinds of Technology Assessment influence the trajectories of research and development. They do so in as far as scientists in the sphere of research have to comply with external, also non-academic and non-scientific scripts. Connected to this is the emergence of scientists being concerned about the public perception of their profession and their work, which several of my respondents voiced.

Hence, agencies external to the structure of science exert varying influence on research, via governmental policies and politics, industry and business preferences, media reports, and the expectation of scientists in regard to the public's perception of science. Therefore, there are two aspects to socio-technoscience. First, the co-production of scientific and social scientific knowledge takes place in technoscience. And second, this happens whilst social elements enter NST via research collaboration and interpretation of other expertise, but also in the co-evolution of the scientific and technological with the public, governmental and commercial influx. Structurally, nanoscale research as technoscience relies not only on physical sciences but increasingly includes social sciences and possibly also humanities whilst drawing from societal interests. The field of NST is formed by scientific and non-scientific, by academic and non-academic contributions and interests.

The concept of socio-technoscience strongly implies that the notion of a 'pure' science, especially in broad fields of application such as NST, is declining. Parallel to this development the emergence of cross-boundary specialisations points towards a decline of the disciplinary structure through science practice. Thus, two aspects seemingly fundamental to academic science are declining in practice.

My respondents sustain an understanding that the distinguishing aspect of academic science, setting it apart from other competing spaces of knowledge production, is actually the notion of 'pure' science. Research in academia, according to their reasoning, allows them to follow research interests purely directed at producing knowledge. To a certain degree that may be so. However, as I have shown, accountability mechanisms in science alone are already changing the rules of the game (cf. Bourdieu, 1987). Also, more and more research in novel research fields is driven towards applications supposed to have societal utility. My analysis highlights what might be seen as contradictions in the current development of academic science, clearly coming out in the differences between what scientists perceive and what they actually practise. These contradictions might provide starting points for understanding the difficulty of clearly opening up science for societal influence on research. Academia is in the process of societal realignment mostly on an administrative basis that remains to fully and comprehensibly permeate research practice. Scientists have to compete for funding and 'prove' the significance of their research ideas as part of a structural and increasingly content-orientated influence called research governance. At the same time, 'pure' science (for example pursuing knowledge without commercial interests) in a disciplinary structure is what sets academia apart from other spaces of knowledge production. Potentially, academic scientists might try to retain definition-power over their actual research and of how research is conducted in their projects, and thus hold on to the notion of 'pure' science as a genuine raison d'etre.

The disciplinary structure of academia might be challenged in science practice. However, it continues to provide an anchor (administratively and epistemologically) for academic science to reproduce and to affirm its position. Disciplines thus contribute to academia's raison d'etre in providing tertiary education and in conducting non-commercial, alongside commercially viable, research. The university in the UK features aspects of a commercial enterprise but remains distinct from other spaces of knowledge production especially in regard to providing undergraduate education. It does perpetuate certain relationships between these aspects. The disciplinary structure of science remains strong in identification processes (providing spaces of 'habitus'), the administration of science and provision of scripts for research conduct. However, in research practice, especially in collaborative projects, the disciplinary structure is regularly ignored. In fact, it needs to be not just ignored but actively 'overcome' to make the most of collaborative research and address complex scientific problems and develop technological applications.

This argument leads to the second main conclusion of my analysis, the epistemological disciplinarity of NST as a specific field of research.

*NST as a Disciplinary Macro-Structure*

One of the main institutional questions I had in mind when commencing this research was whether or not NST is on the verge of becoming a discipline in its own right. However, fieldwork findings have helped me develop an understanding of NST as a specific yet wide field of research, which provides, but also necessitates, specific knowledge, skills and methods as well as tools and research environments. The focus is on the development of applications, or utilising properties of matter and physics at the nano- and microscale. Many of my respondents called NST a 'tool-box', for others it has become a specialisation in their research. What transgresses these views is the shared interest of researchers in this field of applied science.

Here, my analysis corresponds to and supports that of other commentators. NST is not 'issue-driven' (Nordmann, 2004:51) but problem- and space-orientated. The field draws on many different disciplinary backgrounds and is infused with different epistemological approaches and with divergent methodologies (for example chemistry versus engineering). It is thus very widely dispersed across the scientific map, but the aim is to utilise the specific properties of matter at the nanoscale. Many of my respondents and interlocutors at nano-events did not think that the field qualifies as a discipline. The impression I received from their description of their work and perspective on NST supports the view that nanoscale research still defines only a level of exploration. Nanoscience is the essence of expertise from established disciplines and is thus a convoluted, not a coherent, entity. Nanotechnologies are the application of expertise from many disciplines.

However, a distinct process of institutionalisation has emerged resembling a coherent scientific interest providing certain scripts to follow. Institutes and degree programmes have emerged, platforms of exchange have been labelled 'nano', professorial chairs even have adopted nanoscience or nanotechnology into their denomination. At the same time, these processes are a reflection of specialisation. Professorships of nanoscience and/or nanotechnology and university degrees of nanoscale specialisations still provide mainly for specific disciplines (for examples see *Processes of Institutionalisation* in section 2 of chapter 2). Even journals of nanotechnology seem to focus on certain subject areas and disciplines, as some of my respondents point out. Teaching in nanotechnology and/or nanoscience degree programmes remain based on epistemology from established disciplines; there are few attempts to establish theories of NST.

Thus, in scripts emerging and evolving around the terms and ideas of 'nano', in interaction and negotiation of nanoscale research, the entity of NST is constructed. It is more a *meta-field* or transdisciplinary *macro-structure* than a discipline. And this is the challenging aspect of my considerations of NST as an institution amidst the disciplinary structure of academia. There is no need for a discipline of NST to conduct NST research. It is not simply a process of labelling, but a whole host of ideas, approaches, assumptions, expectations, requirements that come together and evolve in collaborative research and through research governance. In nanoscale research, models of top-down (etching, lithography etc.) and bottom-up (self-assembly, biomimetics etc.) approaches have become 'boundary objects'. They are the very idea of translational and transdisciplinary research and create a subliminal 'habitus', rendering NST a 'trading zone' of the many different contributors. It stands as an example of 'Mode 2' knowledge production, a knowledge production directed at technology production. It implies a constant renegotiation and interpretation of the produced knowledge between the contributing (and benefiting) disciplines, and within the NST research process itself.

Scientists' practice-led understandings of their research in NST contribute to this understanding. So does the notion of converging novel research areas, illustrated in the concept of NBIC (nano-, bio- and information technologies plus cognitive science) to create more profound and enabling technologies. In contrast to expectations and visions discussed in the social scientific debates, physical and clinical scientists mostly regard NST as a broad and unspecific field, focused on the incremental nature of nanoscale research and often careful in regard to future prognoses. NST is narratively bound into the existing disciplinary structure of academic science. The sustenance of disciplinary structures in academic administration and in scientists' identification processes means that cross-over and potential convergence of disciplinary expertise in actual research do not necessarily lead towards the emergence of a new discipline. Instead, boundaries between those disciplines become more permeable as scientists research at the borders of different sciences.

However, the socio-technoscientific entity NST is realised in crossdisciplinary collaboration, a research and policy requirement, as I pointed out in chapters 4 and 5. It provides scripts for actual research practice and the strategic dimension of research outlook. It does not provide a strong structure of belonging for most scientists, even if and when those are working within a research institute that incorporates 'nano' in its name, mission, or research. The research agenda does not provide enough means for a disciplinary structure. Thus, NST is not a discipline, but a structuring institution that is constituted and reproduced in crossdisciplinary practice (compare Bourdieu's 'structuring structure' and 'constructivist structuralism' as discussed in Chouliaraki and Fairclough, 2000). My research suggests an interactively pursued permeation of NST with driving linguistic references to, for example, 'nano' and 'interdisciplinarity'. These references (the language of NST) are based on and embedded in existing scientific structures and research, which provide the means for the perpetuation of 'nano' in science policy and debates (both social and scientific) in NST. Thus, I argue, the field is a constructed and constructing macro-structure.

Because NST as an entity is constructed and negotiated by scientists in research practice, the third main conclusion of my analysis concentrates on the disciplinary nature of NST collaboration and its constituting power for nanoscale research.

*NST as a Crossdisciplinary Practice-Constructed Space*

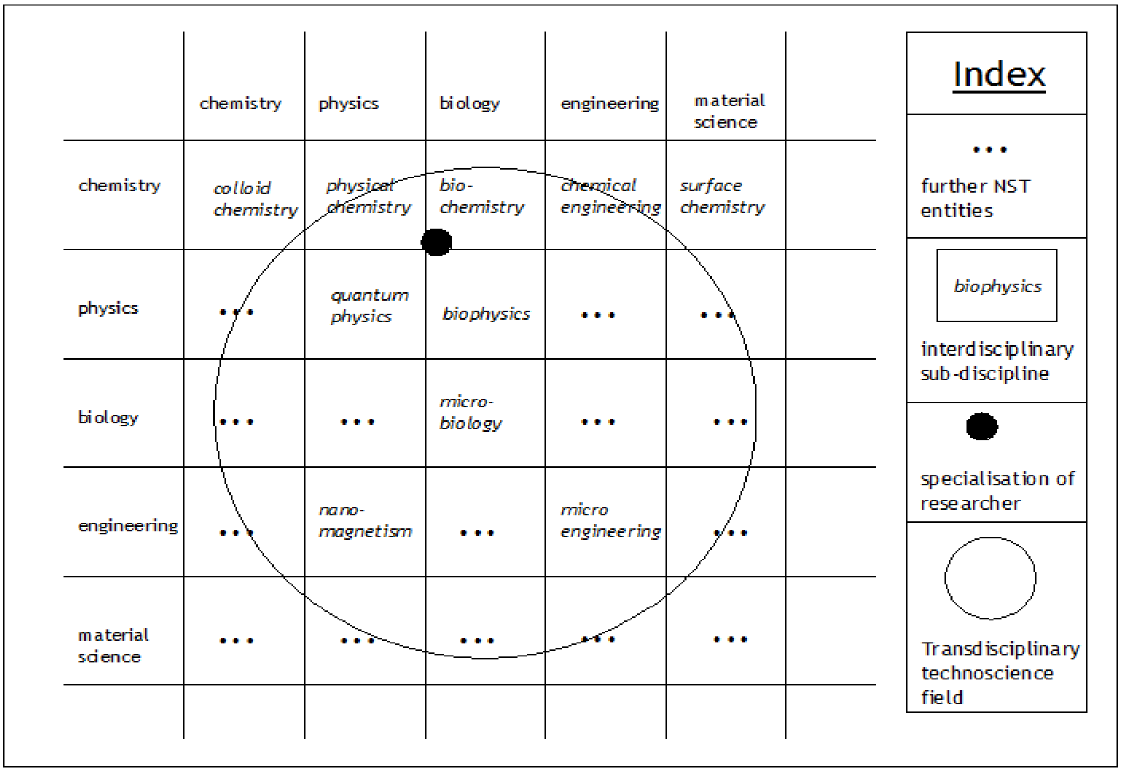
What is the disciplinary nature of NST, what kind of disciplinary concept describes NST best? As I pointed out above, NST is not a discipline. It is a script-providing institution that draws on the contributing epistemology and expertise from many established disciplines and sub-disciplines. Therefore, research practice provides the means to explore this question. Schummer (2004b) describes the scientific nature of nanoscale research as mostly multidisciplinary, resting his analysis on a study of contributions to closed platforms of exchange: nanotechnology periodicals. The interdisciplinary nature of NST is widely argued (Arnall, 2003; Wood *et al*, 2003), pointing at the necessary synergy of methods, expertise and tools from different contributing academic disciplines to exploit the potential of the nanoscale. Nowotny's consideration of transdisciplinarity in contemporary knowledge production (2003) implies a transdisciplinary nature for NST. However, as I suggested before, the last concept especially has no widely shared and accepted definition. Some authors emphasise the problem-orientation and non-disciplinarity (for example Nowotny), whilst others such as Giri (2002) understand the concept as a synergy of disciplinary and non-disciplinary input, a synthesis of interdisciplinarity and personal convictions. All three concepts of disciplinarity describe the structure of processes (how knowledge is produced) and of content (what knowledge is produced) in the social scientific debate. The foci of these three are *contribution* in multidisciplinarity, *synergy* in interdisciplinarity and *problem* in transdisciplinarity.

Considering the broad range of NST, its activities and agendas, it becomes difficult to focus on the disciplinary aspect. There is little doubt that for a field such as NST interdisciplinary research is indispensable. However, a good share of the research taking place in the field seems still multidisciplinary, especially (1) on platforms of closed exchange, (2) when considering contributing science, which is still presented along disciplinary lines both on platforms of exchange and in scientists' identities, and (3) when looking at current technologies making up the major share of nanotechnology production. For example: nanoparticles alone, without their further integration into technology, can be produced by limited crossdisciplinary collaboration. Nanoscale technology production, however limited the synergistic element of collaboration might still be, is developing towards integrated applied technology. It requires interaction between researchers from different backgrounds. Therefore, a distinction needs to be made between what can be described as nanotechnology production *per se*, and applied technology production, in which nanotechnology is connected to the macro-world by integration into micro- and macroscale devices.

Collaboration, then, seems mostly multidisciplinary at the basis of NST. The same applies to coordinating or co-operating engagement between representatives from different disciplines with little direct contact or work-package over-crossing. This limited level of collaboration and basic nanoscale research are examples of a not fully integrated NST knowledge and technology production. However, the expertise of NST-researchers itself becomes more interdisciplinary in the sense of being *paradisciplinary* (cf. Wienroth, forthcoming). The suffix 'para' here stands *not* for a contrast (as in paranormal), but for comparison (as in parable), selection (as in parameter) and adaptation (as in paramilitary). Elements from collaborators' expertise are integrated into one's individual repertoire of knowledge, skills, methods and tools. An identity-practice shift becomes apparent, rather than a practice-identity shift. Aspects of identity adapt and researchers expand their expertise by modifying their knowledge and skills to include the ideas and potentials of NST into their research. Changing a research agenda towards NST already requires adaptation to describe or interpret potential research and existing expertise into NST-compatible and emerging expertise. This also applies to the re-negotiation of research agendas due to a re-attribution of terms and concepts.

Transdisciplinarity features in two regards in NST: its problem-focus, and the combination of practical research taking place in a crossdisciplinary arena. Apparently, this arena lies outside the disciplinary constitution of academic science. After all, collaborations take place across institutional boundaries with industry and other spaces of knowledge production as implied in the transdisciplinarity of 'Mode 2' knowledge production. However, the knowledge aspect, in conjunction with the epistemological *instrumentarium* of research – expressed in expertise – is the bridging element here. The research taking place in NST as a conglomerate of applied science and technology production (technology transfer) feeds back into the disciplinary structure. It does so via adapting and emerging expertise; the subdivision of disciplines; and emerging linkages between and across disciplinary structures. This is a general feature in the convergence of sciences and technologies in application-orientated research.

**Figure 2: Disciplinary Structure of NST as a Transdisciplinary Research Field**




[This basic diagram developed out of a meeting with Frank van der Most (Twente University), to whom I am grateful for our discussion on the disciplinary structure of NST.]

At the same time, the disciplinarity of researchers' backgrounds still plays a role in research collaboration. It provides an identity-foothold in less and less disciplinary orientated research practice, and a positioning tool for researchers in relation to their partners in collaboration, and to competitors in knowledge production.

Thus, the disciplinary nature of science remains in transdisciplinary research. Collaboration difficulties in NST often evolve around disciplinary (epistemic) differences and how these affect the way a problem can be approached and how results are negotiated (see section 4 of chapter 5). Another important factor is personal relationships in collaboration. Personal agendas and motivations play a major role in science conduct (see section 5 of chapter 5). They can have a considerable impact on the epistemological and vice versa. Preferences, attitudes, approaches and disciplinary scripts influence research and the whole of a research project: the development of the overall research agenda; the input of collaborators; the achievable results. In transdisciplinary research epistemological and personal dimensions come together with a problem focus and a collaborative structure of specific interactional requirements and expectations.

Here, Giri's proposal of a 'creative transdisciplinarity' (2002) can provide an element for a more fundamental and comprehensive understanding of transdisciplinarity. Collaborative research benefits from participants being open for new ideas and contributions from collaborators, fostering creativity and learning. This is based on the ability to negotiate epistemological contributions. Outcomes from collaboration on both epistemological and personal levels will feed back into researchers' expertise but also into the disciplinary entities they come from. It can be argued, then, that NST as a disciplinary macro-structure requires disciplinary diversity both in regard to its contributing frameworks and to the practice that is constituting NST as an entity.

*Discipline NST?*

This, however, leaves us with the question whether NST *can* become a discipline in its own right. Will it instigate the emergence of sub-disciplines in other disciplines? Or simply benefit from the emergence of such entities in a circular feedback exchange between the established disciplines and the field NST? An answer to the question of disciplinarity can have effects on the understanding of NST as well as on disciplinarity in academia generally. If NST does not become a discipline, the field remains malleable and open to many novel ideas, but also to digressing ones. This can weaken the momentum of NST. For academia and disciplinarity it can mean that the notion of disciplinarity may be weakened further if research in this field can be successfully conducted and implemented. If NST does become a discipline, the idea of compatible paradigmatic epistemologies within one discipline (in line with Thomas Kuhn) is threatened as diverse epistemological currents currently inhabit the field of NST.

*NST and 'Mode 2'*

In summary, in order to understand the current and emerging disciplinary nature of NST, it is necessary to clarify the dependence of its structure on its practice. Collaborative practice and research policies supporting NST create a space for the field, thus contribute to its construction. Although the focus of this analysis is on academia as a space of NST research, it has become apparent that NST practice – and collaboration lies at the focal point of this perspective – is influenced by other societal spaces and agencies of knowledge production, and can be described as a case of the 'triple helix', where academia, industry and government jointly contribute to knowledge production. In this regard, also, my analysis supports the concept of 'Mode 2' and the notion of transgression of disciplinary boundaries in NST research, its agenda-setting and its trajectories. Even non-scientific societal spaces (media, the general public, governmental policy-makers and funding providers) exert influence on the structure of science by indirectly impacting on scripts of research conduct, or on the way science is narrated by its protagonists in regard to NST's role in society. This can be understood in terms of scientific and societal 'co-production' (cf. Jasanoff, 2006), and 'reflexive co-evolution' (Rip, 2005) of science and societal interests. These are introduced to the research process in several ways. First, scientists' legitimation of academic science includes the notion of producing knowledge for the good of society. Second, in collaboration with non-academic scientists, non-academic and even non-scientific interests and scripts are introduced to academic science practice (commercial etc.). Third, proliferating agencies of societal accountability such as ELSA, Technology Assessment and so forth, influence the governance of science, and as such also the negotiation of science. NST provides a very good example.

However, my analysis does not necessarily support the strict evolutionary connotation of 'Mode 2' and the break-away of disciplines. The existing disciplinary structure of academia remains a strong identity dimension for researchers in NST for the time being. NST research rests on contributing expertise, and its conduct and findings feed back into contributing disciplines. It provides a space for visions and ideas rather than models, and specified scripts instead of an epistemology. The field has emerged from scientific and technological development, and it provides such development in applied science and technology. The practice of research in NST is thus the lowest common denominator for the coherence of the field's structure. As of now, established disciplines provide and claim the basic and theoretical aspects of research at the nanoscale.

In this section I have drawn out the main conclusions of my analysis, in relation to the social scientific debate around changing science structure and practice. Through my considerations here I have also refined understandings of three major first order disciplinarities of science practice: multi-, inter- and transdisciplinarity. In the following section I consider wider questions for future research emerging from my analysis.

## 4 Further Questions for Academia

There are many wider questions that would help improve understanding of the structural emergence and reproduction of NST. Their uptake may also provide more insights into how the field is sustained when described as just a 'tool-box' (by scientists) or a matter simply of scale. I point out a few here, indicating future research that might follow-up on this analysis.

*Question of Owning Crossdisciplinary Knowledge*

Two questions closely related to the structural nature of NST regard (1) the disciplinary allocation of inter- and transdisciplinary knowledge and technology, and (2) the notion of 'pure' science that seemingly still holds considerable capital among scientists. The first question refers to disciplinary feedback from nanoscale research, as put forward by Strathern. She asks where interdisciplinary knowledge belongs epistemologically (2004), and what this might imply for the constitution of a community (2006). Slightly broadening the scope of these questions, it would be interesting to explore where inter- and transdisciplinary knowledge and technology belong in the epistemological frameworks of academic science, possibly how they can contribute to consolidating NST. This could be done either in a contextualising extradisciplinary or a comparative paradisciplinary way (for an overview of non/para/extradisciplinarity as second order concepts see Wienroth, forthcoming). Other approaches are focused on bibliometric techniques (Schummer, 2004b) or on exploring the 'patent thickets' and intellectual property issues in nanotechnology (Clarkson and DeKorte, 2006). In my analysis of the disciplinary structure of NST I have pointed out that scientists still identify with the disciplinary background they acquired through training. However, it is their research practice that constitutes the field of nanoscale research. Nevertheless, findings from NST research seem to feed back into established disciplinary frameworks. But how do researchers interpret, translate and incorporate the findings and results from nanoscale research in their disciplinary framework? That is, how do they own crossdisciplinary knowledge?

*Question of 'Pure' Science*

Connected to this issue is the question of the 'destiny' of 'pure' science and the potential exploration of its (future) raison d'etre. Is it the notion of 'pure' science that makes academic research so attractive? Is this notion the major driver for why researchers still do research despite increasing regulatory regimes and efforts in accessing funding? On the other hand, is the changing academic world providing further new incentives for scientists to become academics, for example through opportunities to take research into application and even commercial contexts? One aspect of 'pure' science is the attempted stripping down of societal aspects in research, what Johansson describes as the “extramural” (2008:80) that would interfere with scientific conduct. This could support a strongly toned down notion of 'pure' science. However, non-scientific elements of researchers' lives are not simply shut out in science practice, as, for example, Howard Ecklund and Scheitle demonstrate in their study on “Religion among Academic Scientists” (2007). Societal interests are involved in the agenda-setting and influence the trajectories of research. However, the societal constituents of research are ignored or translated into scientific scripts. One reason is that scientific and technological state-of-the-art has a strong impact on what and how research can be undertaken. The colour 'red' becomes an entity of photons with a wavelength of 650 nanometres that needs to be, but also can be measured accurately. Aesthetic, emotional and symbolic aspects are neglected. At the same time, actual societal application is transferred to outside of academia. However, this division of the social and the technical might collide with the idea of culturally determined and differing approaches to science in general (cf. Fuller, 1997), and would contradict with the increasing applied research taking place within the university. At the same time, this apparent contradiction makes this question so interesting. Is the concept of 'pure' science itself changing?

*Question of the Un-Scientific in Science*

To further this point, one can look at the range of non-scientific aspects that impact on scientists' narratives of their research. Part of non-scientific aspects are what some of my respondents describe as 'un-scientific', that is contra-scientific aspects. Some aspects of NST-narratives advanced by nano-enthusiasts like Drexler, Freitas or Kurzweil, but also by pessimists just as Joy and the ETC Group, have been rejected as Science Fiction or scientifically unsound, both by my respondents and by some of the literature discussing the field. The accounts of my respondents indicate that these are perceived as 'un-scientific'. At the same time, the individuals listed above are scientists themselves. This implies that some scientists include not just non-scientific but 'un-scientific' elements in their accounts on science, possibly to promote agendas and personal (research and other) ideas. It also implies that researchers have to deal with 'un-scientific' aspects in research practice, visible in scientists' rather gloomy anticipation of the effects of such accounts on the public and science policy. Policy decisions or other external requirements can have a contra-scientific affect on scientific expertise as suggested by Konopásek *et al* (2008) in regard to the politicisation of scientific 'facts' in real world problems. In a similar thrust, Haller and Gerrie (2007) suggest that there are two kinds of science being conducted in the context of the knowledge society: 'pure' science and science for policy. Both are strongly interconnected when scientific expertise enters the public domain. The two papers mentioned above discuss how scientific accounts ('facts') are being managed in the public domain, the first how scientific expertise is 'bypassed', the second how it becomes 'for hire'. However, this begs the question, then, of how 'un-scientific' elements come to feature in accounts of science *within* scientific practice, and how they influence both scientific conduct (and, again, 'pure' science) and its representation within and outside science?

*Question of Funding Bodies and NST*

This connects to the question of the relationship between NST and funding. Very early on, in chapter 2, I pointed out that there are many contributors to the narrative of NST. Later on I suggested that the structure of NST rests on the practical aspects of research and identity, and that science governance agencies' decisions impact considerably on science practice. Therefore, it would be appropriate to expand the view of agencies contributing to NST by turning towards funding and agenda-setting organisations such as, in the UK, the Research Councils. UK funding bodies, particularly the Research Councils, have been described by some of my respondents as gathering their understanding of NST from scientists in the field. At the same time, scientists in NST have criticised the fact that public funding for nanoscale research has been distributed in a rather arbitrary fashion. It has often supported research based within established disciplinary boundaries but labelled as NST, or research that is 'not really' NST. But how do funding organisations come to an understanding of NST? This seems especially significant in the case of public funding, and in regard to the scrutiny under which scientific research finds itself in regard to risks, benefits and broader societal aspects. Through which means and from what sources do funding bodies acquire their understanding of NST? From scientists' application proposals describing their uptake of what the funder might want to fund? From scientists in the reviewing process or in an advisory function? How do funding bodies narrate NST: how do *they* account for funding in the field and represent the field, for example in their own literature and other forms of presentations? These questions are at the heart of funding policies. For the case of the UK Research Councils the enquiry would point towards exploring how sources and understandings might change over time. Is there a response to new scientific findings, or policy changes, for example in concert with EU research policy? Also, do debates around NST have an impact on how the field is perceived when it comes to funding decisions?

*Summary Question of Academia's Position in Society*

Only recently, a debate has rekindled in regard to what academic science is about, basically a revival of debates about what constitutes 'pure' science. I have mentioned Jotterand's (2006) and Moriarty's (2008) papers before, and I have referred to the public debate on 'academic' and 'post-academic' science in academia, organised by DEMOS in London in May 2008. At the meeting, a brief but heated exchange took place between a researcher on the panel and two representatives from a Research Council in the audience. Both sides displayed contrasting views on the funding practice in the specific area of that scientist and the Council. This underscores what some of my respondents said, that scientists and funding bodies apparently have, at times, very diverse understandings of what is being funded, how and why.

Therefore, the overarching question for these past points really seems to be how science can bring (1) the production of basic scientific knowledge and (2) applications and policy advice into equilibrium. The very existence, the raison d'etre of academia is perceived to be at stake, when basic research is considered to be suffering from a move towards increased funding for applications. Arguably, academia has a place in society for providing and mediating knowledge for the wider public. It also seems very plausible that academia needs to remain a societal space for producing basic and novel knowledge (which might lead to further innovation and to technology transfer), and for producing knowledge and technology that might not have commercial utility. How, then, can the scientific and the societal be brought together without risking the productivity and novelty of science, whilst sustainably and openly embedding scientific research and its practice in its societal context?

The ideas presented here not only shed light on the analytical breadth of exploring contemporary science as I have done in this thesis, but also supply further grounds to apply and possibly expand the analytical tools I have developed in the previous three chapters. The structural and practice-orientated approach I have taken has provided certain advantages and resulted in some apparent omissions for this analysis. However, I propose that the three major themes of *research identity* and *collaboration* (constituting research practice) and *disciplinarity* enable an understanding of the sometimes contradictory nature of NST as a case in point of the change in contemporary academic structure and research practice. I discuss the generalisability of NST for academic science in the next section. Exploring how the field is constituted and reproduced contributes to the understanding of existing motivations for NST research. It also supports aspirations to identify and examine emerging agendas, scripts and accountability mechanisms. This approach further provides grounds for the formulation of future research agendas and policies of socio-technological knowledge production.

## 5 The Lowest Common Denominator – In NST *and* Academia?

NST features many aspects that allow it to be compared with other fields of new and emergent science and technology. As I pointed out in chapter 3 (*Links between NST and Biotechnology* in section 8), there are strong connections between NST and the vast field of biotechnology, both in structure and in practice. Both fields have considerable implications for the development of academic science, namely that applied science connects basic science much stronger with technology transfer than previously. This connection is at the core of the notion of technoscience, and it is strongly fostered through science governance (policy and funding).

My research suggest that elements of NST as an emergent research field can be applied to the vast range of academic sciences. It can be argued that there are two approaches to understanding the generalisability of NST: (1) the field is a socio-technoscientific macro-structure drawing from and contributing to established disciplines, and (2) NST has emerged as a practice-constructed macro-structure with distinct features. Both seem contradictory at first glance, but interconnect through science practice. One of these links is the technoscientific development I mentioned above. My data strongly indicates that NST science practice has evolved from other sciences whilst also feeding back to other sciences. However, the structure of NST is different to established sciences, but similar to other emergent fields of science and technology. These two elements provide an understanding of NST as embedded within the ongoing development of (academic) science whilst showing that it is still distinct in its structural nature.

*Generalisable Features of NST*

The questions I considered in the previous section provide a context for the generalisability of many aspects of my analysis of NST. The emerging disciplinarity in NST science practice, in particular, is an element that is generalisable. Another is science governance, which becomes particularly strongly visible in NST with the fostering of nanoscale research, but also the increasing accountability for research. Indeed, these examples show that NST needs to be generalisable as otherwise the field would not be connected to previous and ongoing academic science, and could thus not emerge from and contribute to it.

Researchers' increasingly interdisciplinary research specialisations are a significant aspect of science practice. As I identified in chapter 4, researchers tend to work on and across the borders of different sciences. These researchers do not necessarily affiliate with NST but consider themselves to be doing research at the micro- and nanoscale where much of current NST research is taking place. The recurring reference to 'nano', the use of certain concepts and their specific meanings, the demarcation between science and fiction, among others, are elements that constitute the uniqueness of the NST structure, but provide comparisons for the way the field is negotiated within other fields in science.

Also, the crossdisciplinarity of collaboration is an aspect that expands into many areas of science. This seems due to the increasing complexity of producing new knowledge. Ideas of systemic approaches to the material world permeate science, especially in biological and chemical sciences, which become apparent in scientists' aspirations (in the literature for example Ball, 2002; Whitesides, 2001; Whitesides and Love, 2001) but also in emergent areas such as systems biology (cf. Marcum, 2008), synthetic biology (cf. Ball, 2004) and nanobiotechnology (cf. Soloviev, 2007; Zhao and Zhang, 2007). These areas rely on many overlapping (sub-)disciplines such as biophysics, biochemistry, physical chemistry and so on. All of these also contribute to NST in one way or another, and thus constitute the field.

I believe it is these two aspects that are of particular relevance for understanding NST in the context of contemporary academic science, but also for understanding where academic science might be headed in the near to mid-term future. NST can thus contribute to the understanding of academic science practice, and also for understanding scientists and their *Lebenswelt* (or socio-technological worlds, see chapter 4) in science and in society.

In my early consideration of how scientists from different disciplinary backgrounds (epistemic cultures) might negotiate their identity in a 'trading zone', or how NST might even become a new discipline, I came across Robert E. Park's notion of the 'marginal man' (cf. Stoneqvist, 1935). “The marginal man arises in a bi-cultural or multi-cultural situation” (*ibid.*:1). The interesting idea for me was not the connotation of race, of course, but the idea of cultural adaptation and the potential emergence of a new framework. The field of marginalisation lies outside my field of expertise, but it features aspects that could be interesting and helpful in future research. For example: what might 'marginality' mean for scientists working in so widely debated a field such as NST, where so many non-scientific considerations influence the negotiation of the field? The position of these scientists may be comparable to the initial position of 'marginalised groups' as shown in McLaughlin and Goodley's study of parents with disabled children (2008:318). The 'outside world', it appears, places these groups in a certain position but the groups themselves do not necessarily perceive to be in that particular position. Scientists may be attributed a taken-for-granted position of controlling all aspects of knowledge production. However, especially in novel research fields such as NST, they have to continuously negotiate their experiences, thus their *Lebenswelt*, in response to existing and changing elements (for example academic disciplinary structure, science practice). Every-day practice and identification processes, then, seem to be at the core of both my study and those on understanding marginalised groups such as by McLaughlin and Goodley (cf. 2008:320f and 331), but also in the debate around the 'marginal man'. I have referred to the potential marginality of scientists for three reasons: (1) to relate NST research to research in other fields, (2) to provide a further argument for why the study of science needs to examine science practices and include voices of science actors, and (3) to show a potential theme for future research connecting to my study. For the third reason, of course, there is a vast amount of literature on marginalisation to be considered.

*Models from NST*

Disciplinarity and collaboration are two main pillars of my analysis. During my fieldwork, and drawing from various literature on NST, biotechnology, academic-industrial collaboration, and disciplinarity, I have developed two preliminary analytical approaches to expand the understanding of these two pillars. They are applicable in other contexts than NST, as well, as they are analytical approaches based not only on my research but drawing from different models and usages of terms and concepts.

In section 7 of chapter 4, and in section 3 of this chapter, I refer to aspects of disciplinarity that can be described as 'second order', or analytical, disciplinarities. They can provide further means to understand the disciplinary structure of how different disciplinary expertise are correlated in disciplinary practice. The latter can be approached by relying on concepts of crossdisciplinarity. These are generally multi-, inter- and transdisciplinarity. Concepts to explore the structural dimensions of disciplinarity are, I propose, non-, extra- and paradisciplinarity. These are based on notions used in the wider social scientific literature (Hearn, 2003; Osbourne, 2002), and on Oksaar's cultural theory of verbality (1988). Paradisciplinarity is a concept that I elaborated on before in length to understand scientists' specialisations. In Table 3, I give an account of different interpretative repertoires of disciplinarity that can be held simultaneously. They feature in scientists' narratives on their own specialisations and the disciplinarities enacted in the field of NST.

**Table 3: Axioms of Second Order Disciplinarities**

| **Disciplinarity** (second order) | **Function** (towards understanding disciplinarity) | **Focus** (of analysis) |
|---|---|---|
| nondisciplinarity | contrasting | problem |
| extradisciplinarity | contextualising | structure |
| paradisciplinarity | comparing | approach |

In addition to these concepts, I have considered a level-model of collaboration. In chapters 1 and 2 I refer to notions of collaboration that inform my usage of the concept (Corley *et al*, 2006; Frey *et al*, 2006; Polenske, 2004). In chapter 5 I examine scientists' accounts on what role collaboration has in NST, and how their identities are influenced by crossdisciplinary projects. From both, I have drafted a matrix (Table 4) that describes certain collaborative levels through institutional indicators. The aim of this matrix is to provide the basis for developing a model of institutionalisation through collaboration, derived from Hogue's model of community-based collaboration (1993). Collaboration can be seen as an institutionalisation process requiring a certain time scale for epistemological acclimatisation and methodological adaptation for disciplinary backgrounds involved.

**Table 4: Collaborative-Institutional Matrix**

| | **Institutional Dimensions** | | |
|---|---|---|---|
| **Levels** | *Epistemic Proximity* | *Regulatory Framework* | *Communication* |
| *Coordination* | distant/foundational | informal network | individual/informal |
| *Cooperation* | aggregated/compatible | partnership/project | regular/formal |
| *Collaboration* | close/synergistic | exclusive trading zone | constant/formal |
| *Coalescence* | shared/unified | institutionalised/membership | institutionalised |

Both analytical approaches provide means to expand the social study of contemporary knowledge production in new and emergent fields of science and technology in regard to their disciplinarity and their institutionalisation. A key issue for future analysis is how to mould the two tables of disciplinarity and collaborative institutionalisation. Simultaneously, these approaches, drawn from findings of this case study of NST in the North-East of England and its international connections, link this case study and NST into the wider debate of academic science, which has been refuelled in the notion of 'Mode 2'.

*Features of NST not Generalisable*

However, NST is also a unique case (so far) in several respects. These are connected to the field's nature of being a macro-structure that is negotiated through its particular practice and requirements from science governance, not through strong individual affiliations or even a coherent epistemic culture. The state of epistemological differences in NST, for example, is difficult to generalise for individual disciplines. The differences of contributing epistemologies are broad so that a specific NST epistemology has not yet emerged. Individual sub-fields of NST might be able to adhere to a common epistemic understanding, but are then more often than not connected to more traditional disciplines.

The difficulty of providing an epistemic 'home' might contribute to another aspect that seems quite unique to NST: its 'denial'. This can be a regional idiosyncrasy of my case study, considering the views of some of my respondents regarding the 're-labelling' of existing institutions into 'nano', and the funding policies executed in the North-East of England. However, also in wider scientific debates in the literature, researchers seem to take their 'critical distancing' further than in other fields (for agricultural biotechnology see for example Burchell, 2007), leading to very careful demarcation, such as describing NST as a 'tool-box'. Not all of my respondents do so, in fact many see more in it than that. But, as Researcher18 said, one has to be “brave enough” to commit to NST.

## 6 Concluding Remarks

The overall aim of my research has been to explore and form an understanding of NST as a field of new and emergent science and technology in academic science. In section 2 of this chapter I have discussed my findings from the subsidiary research questions, and in section 3 I have suggested overall conclusions in response to the main question of my study. Briefly summarising these conclusions, the field of NST can be understood as a macro-structure of scientific knowledge and technology production. It is constituted in the collaborative interaction of researchers' crossdisciplinary specialisations, aiming to address real world problems. Contributing to the field's construction, and thus its dichotomous socio-technoscientific nature, are policy debates and societal interests from the outside of the sphere of research, that is from science governance, social sciences, and the public sectors of the 'knowledge society'. NST is an example of the increasing co-production of scientific and societal interests, and for the development of two distinct types of academic research, which are nonetheless deeply interconnected.

# Bibliography


**Abbing**, H. (2007) *Why are Artists Poor? The Exceptional Economy of the Arts*, Amsterdam: Amsterdam University Press.

**Aberbach**, J.D., Rockman, B.A. (2002) 'Conducting and Coding Elite Interviews', *Political Science and Politics* **35**(4) 673–676.

**Andrew**, G., McMullen, L.M. (2000) Interpersonal Scripts in the Anger Narratives Told by Clients in Psychotherapy, *Motivation and Emotion* **24**(4), 271–284.

**Andrews**, M. *et al* (2004) 'Narrative Research', in: Seale, C. *et al* (eds) *Qualitative Research Practice*, London: SAGE, 109–124.

**Arnall**, A.H. (2003) *Future Technologies, Today's Choices. Nanotechnology, Artificial Intelligence and Robotics. A Technical, Political and Institutional Map of Emerging Technologies*, London: Greenpeace Environmental Trust.

**Ball**, S. (2002) 'Natural Strategies for the Molecular Engineer', *Nanotechnology* **13**, R15–R28.

**Ball**, S. (2004) 'Synthetic Biology for Nanotechnology', *Nanotechnology* **16** (2005) R1–R8.

**Baszanger**, I., Dodier, N. (2004) 'Ethnography. Relating the Part to the Whole', in: Silverman, D. (ed) *Qualitative Research. Theory, Method and Practice* (2nd edition), London; Thousand Oaks: SAGE, 9–34.

**Bennett**, M. (2004) 'Does Existing Law Fail to Address Nanotechnoscience?', *IEEE Technology and Society Magazine* (Winter 2004) 27–32.

**Bensaude-Vincent**, B. (2004) 'Two Cultures of Nanotechnology?', *International Journal for Philosophy of Chemistry* **10**(2) 65–82.

**Bhushan**, B. (ed) (2004) *Springer Handbook of Nanotechnology*, Berlin; New York: Springer.

**Bloor**, M. (2004) 'Addressing Social Problems Through Qualitative Research', in: Silverman, D. (ed) *Qualitative Research. Theory, Method and Practice* (2nd edition), London; Thousand Oaks: SAGE, 305–324.

**Bogner**, A. (2005) 'How Experts Draw Boundaries. Dealing with Non-Knowledge and Uncertainty in Prenatal Testing', *Science, Technology and Innovation Studies* **1** (July 2005) 17–37.

**Bourdieu**, P. (1987) *Die Feinen Unterschiede. Kritik der Gesellschaftlichen*

*Urteilskraft*, Frankfurt/Main: Suhrkamp.

**Brehen**, M. (ed) (2002) *The Japanese Experience – Inevitable*, Kraichtal: Ursula Blickle Foundation.

**Bruce**, D. (2005) *Nano-2-Life Ethics. A Scoping Paper on Ethical and Social Issues in Nanobiotechnologies* (delivered to Nano-2-Life), Edinburgh.

**Bueno**, O. (2004a) 'Von Neumann, Self-Reproduction and the Constitution of Nanophenomena', in: Baird, D., Nordmann, A. and Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 101–115.

**Bueno**, O. (2004b) 'The Drexler-Smalley Debate on Nanotechnology. Incommensurability at Work?', *International Journal for Philosophy of Chemistry* **10**(2) 83–98.

**Bulmer**, M. (2001) 'The Ethics of Social Research', in: Gilbert, N. (ed) *Researching Social Life* (2nd edition), London: SAGE, 45–57.

**Burchell**, K. (2007) 'Boundary Work, Associative Argumentation and Switching in the Advocacy of Agricultural Biotechnology', *Science as Culture* **16**(1) 49–70.

**Burgess**, R.G. (1982) 'Elements of Sampling in Field Research', in: Burgess, R.G. (ed) *Field Research. A Sourcebook and Manual* (Contemporary Social Research Series Vol. 4) London: Routledge, 75–78.

**Burgess**, R.G. (1984) *In the Field. An Introduction to Field Research* (Contemporary Social Research Series Vol. 8) London: Routledge.

**Caves**, R.E. (2003) 'Contracts Between Art and Commerce', *Journal of Economic Perspectives* **17**(2) 73–83.

**Charlton**, B.G., Andras, P. (2005) 'The Future of 'Pure' Medical Science. The Need for a New Specialist Professional Research System', *Medical Hypotheses* **65**(3) 419–425.

**Charlton**, B.G. (2006) 'Why Medical Research Needs a New Speciality of 'Pure Medical Science'', *Clinical Medicine* **6**(2) 163–165.

**Chase**, S.E. (2005) 'Narrative Inquiry. Multiple Lenses, Approaches, Voices', in: Denzin, N.K., Lincoln, Y.S. (eds) *The SAGE Handbook of Qualitative Research* (3rd edition), London: SAGE, 651–679.

**Chouliaraki**, L., Fairclough, N. (2000) 'Language and Power in Bourdieu. On Hasan's “The Disempowerment Game”', *Linguistics and Education* **10**(4) 399–409.

**Clarkson**, G., DeKorte, D. (2006) 'The Problem of Patent Thickets in Convergent Technologies', *Annals of the New York Academy of Science* **1093**, 180–200.

**Corley**, E.A., Boardman, P.C., Bozeman, B. (2006) 'Design and the Management of

Multi-Institutional Research Collaborations. Theoretical Implications from two Case Studies', *Research Policy* **35**, 975–993.

**Cotgrove**, S. (1970) 'The Sociology of Science and Technology', *The British Journal of Sociology* **21**(1) (March 1970) 1–15.

**Crespo**, M., Dridi, H. (2007) 'Intensification of University–Industry Relationships and its Impact on Academic Research', *Higher Education* **54,** 61–84.

**Cronin**, A. (2001) 'Focus Groups', in: Gilbert, N. (ed) *Researching Social Life* (2nd edition), London: SAGE, 164–177.

**Department of Innovation, Universities and Skills** (DIUS) (2008) *Innovation Nation. Unlocking Talent* (White Paper, March 2008) HM Government (UK).

**Department of Trade and Industry** (DTI) (2005) *Response to the Royal Society and Royal Academy of Engineering Report 'Nanoscience and Nanotechnologies. Opportunities and Uncertainties'* (February 2005) HM Government (UK).

**Deuten**, J.J., Rip, A. (2000) 'Narrative Infrastructure in Product Creation Processes', *Organization* **7**(1) 69–93.

**De Vries**, M.J. (2005) 'Analyzing the Complexity of Nanotechnology', *Techné: Research in Philosophy and Technology* **3**(8) 165–179.

**Diani**, M. (2000) 'Simmel to Rokkan and Beyond. Towards a Network Theory of (New) Social Movements', *European Journal of Social Theory* **3**(4) 387–406.

**DiMaggio**, P.J., Powell, W.W. (eds) (1991) *The New Institutionalism in Organizational Analysis*, Chicago: University of Chicago Press.

**Doubleday**, R. (2007a) 'Organizing Accountability. Co-Production of Technoscientific and Social Worlds in a Nanoscience Laboratory', *Area* **39**(2) 166–175.

**Doubleday**, R. (2007b) 'Risk, Public Engagement and Reflexivity. Alternative Framings of the Public Dimensions of Nanotechnology', *Health, Risk & Society* **9**(2) 211 – 227.

**Drexler**, KE. (1990) *Engines of Creation. The Coming Era of Nanotechnology*, New York: Anchor Books.

**Drexler**, K.E. (1995) 'Introduction to Nanotechnology', in: Krummenacker, M., Lewis, J. (eds) *Prospects in Nanotechnology. Toward Molecular Manufacturing*, New York: John Wiley, 1-22.

**Dupuy**, J.-P. (2007) 'Some Pitfalls in the Philosophical Foundations of Nanoethics', *Journal of Medicine and Philosophy* **32**, 237–261.

**Einsiedel**, E.F., Goldenberg, L. (2004) 'Dwarfing the Social? Nanotechnology Lessons

From the Biotechnology Front', *Bulletin of Science, Technology and Society* **24**(1) 28–33.

**Esparza**, J., Yamada, T. (2007) 'The Discovery Value of "Big Science"', *The Journal of Experimental Medicine* **204**(4) 701–704.

**Etzkowitz**, H., Leydesdorff, L. (2000) 'The Dynamics of Innovation. From National Systems and "Mode 2" to a Triple Helix of University-Industry-Government Relations', *Research Policy* **29**(2) 109–123.

**European Science Foundation** (2005) *Nanomedicine. An ESF – European Medical Research Councils (EMRC) Forward Look Report*, Strasbourg: ESF.

**Fielding**, N., Thomas, H. (2001) 'Qualitative Interviewing', in: Gilbert, N. (ed) *Researching Social Life* (2nd edition), London: SAGE, 123–144.

**Fielding**, N. (2001) 'Ethnography', in: Gilbert, N. (ed) *Researching Social Life* (2nd edition), London: SAGE, 145–163.

**Fisher**, E., Mahajan, R.L. (2006) 'Midstream Modulation of Nanotechnology in an Academic Research Laboratory', in: *Proceedings of IMECHE 2006, November 5-10*, Chicago/ IL: ASME.

**Fleck**, L. (1980) *Entstehung und Entwicklung einer Wissenschaftlichen Tatsache. Einfürung in die Lehre vom Denkstil und Denkkollektiv*, Frankfurt/Main: Suhrkamp.

**Fonash**, S.J. (2001) 'Implications of Nanotechnology for the Workforce', in: Roco, M.C., Sims Bainbridge, W. (eds) *Societal Implications of Nanoscience and Nanotechnology*, Dordrecht: Kluwer, 173–180.

**Freitas**, R.A. Jr. (1999) *Nanomedicine, Volume I: Basic Capabilities*, Austin, TX: Landes Bioscience.

**Frey**, B.B., Lohmeier, J.H., Lee, S.W., Tollefson, N. (2006) 'Measuring Collaboration Among Grant Partners', *American Journal of Education* **27**(3) 383–392.

**Fuller**, S. (1997) *Science* (Concepts in the Social Sciences), Buckingham: Open University Press.

**Garot**, R., Katz, J. (2003) **'**Provocative Looks. Gang Appearance and Dress Codes in an Inner-City Alternative School', *Ethnography* **4**(3) 421–454.

**Gavelin**, K., Wilson, R., Doubleday, R. (2007) *Democratic Technologies? The Final Report of the Nanotechnology Engagement Group (NEG)*, London: Involve.

**George**, A.L., Bennett, A. (2004) *Case Studies and Theory Development in the Social Sciences*, Cambridge/MA: MIT Press.

**Giri**, A.K. (2002) 'The Calling of a Creative Transdisciplinarity', *Futures* **34**, 103 – 115.

**Gorman**, M.E., Groves, J.F., Shrager, J. (2004) 'Social Dimensions of Nanotechnology as a Trading Zone. Results from a Pilot Project', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 63–73.

**Guston**, D. (2001) 'Boundary Organizations in Environmental Policy and Science. An Introduction', *Science, Technology & Human Values* **26**(4) 399–408.

**Guston**, D.H., Sarewitz, D. (2002) 'Real-Time Technology Assessment', *Technology in Society* **24**(1-2) 93–109.

**Haimes**, E. (2002) 'What Can the Social Sciences Contribute to the Study of Ethics? Theoretical, Empirical and Substantive Considerations', *Bioethics* **16**(2) 89–113.

**Haimes**, E., Williams, R. (2007) 'Sociology, Ethics, and the Priority of the Particular. Learning from a Case Study of Genetic Deliberations', *The British Journal of Sociology* **58**(3) 457–476.

**Haller**, S.F., Gerrie, J. (2007) 'The Role of Science in Public Policy. Higher Reason or Reason for Hire?', *Journal of Agricultural and Environmental Ethics* **20**, 139–165.

**Haraway**, D. (1997) *Modest_Witness@Second_Millennium: Female_Man©_Meets_ Oncomouse*™, London; New York: Routledge.

**Harré**, R. (1998) 'When the Knower is Also the Known', in: May, T., Williams, M. (eds) *Knowing the Social World*, Buckingham: Open University Press, 37–49.

**Harris**, M. (ed) (2007) *Ways of Knowing* (Methodology and History in Anthropology Series Vol. 18), New York: Berghahn Book, 1–24.

**Hasse**, R., Krücken, G. (2005) *Neo-Institutionalismus* (2nd completely revised edition) (Einsichten. Themen der Soziologie), Bielefeld: transcript.

**Hearn**, A. (2003) 'Interdisciplinarity / Extradisciplinarity. On the University and the Active Pursuit of Community', *History of Intellectual Culture* **3**(1)

**Hedgecoe**, A.M. (2003) 'Terminology and the Construction of Scientific Disciplines. The Case of Pharmacogenomics', *Science, Technology & Human Values* **28**(4) (Autumn 2003) 513–537.

**Honigmann**, J.J. (1982) 'Sampling in Ethnographic Fieldwork', in: Burgess, R.G. (ed) *Field Research. A Sourcebook and Manual* (Contemporary Social Research Series No.4), London: Routledge, 79–90.

**Howard Ecklund**, E., Scheitle, C.P. (2007) 'Religion among Academic Scientists. Distinctions, Disciplines, and Demographics', *Social Problems* **54**(2) 289–307.

**Hullmann**, A., Meyer, M. (2003) 'Publications and Patents in Nanotechnology. An Overview of Previous Studies and the State of the Art', *Scientometrics* **58**(3) 507–527.

**Jacob**, M. (2001) 'Managing the Institutionalisation of Mode 2 Knowledge Production', *Science Studies* **14**(2) 83–100.

**Jasanoff**, S. (ed) (2006) *States of Knowledge. The Co-Production of Science and Social Order*, London; New York: Routledge.

**Joachim**, C. (2005) 'To be Nano or Not to be Nano', *Nature Materials* **4** (February 2005) 107–109.

**Johansson**, M. (2003) 'Plenty of Room at the Bottom. Towards an Anthropology of Nanoscience', *Anthropology Today* **19**(6) (December 2003) 3–6.

**Johansson**, M. (2008) *Next to Nothing. A Study of Nanoscientists and their Cosmology at a Swedish Research Laboratory*, Göteborg: University of Gothenburg.

**Jones**, R.A.L. (2004) *Soft Machines. Nanotechnology and Life*, Oxford: Oxford University Press.

**Jömann**, N. (2004) *Ethical Implications of Nanobiotechnology, State-of-the-art survey of Ethical Issues related to Nanobiotechnology* (paper delivered to Nano-2-Life).

**Jotterand**, F. (2006) 'The Politicization of Science and Technology. Its Implications for Nanotechnology', *The Journal of Law, Medicine and Ethics* **34**(4) 658–666.

**Joy**, B. (2000) 'Why the Future Doesn't Need Us', *Wired* **8**(4).

**Kearnes**, M., Macnaghten, P., Wilsdon, J. (2006) *Governing at the Nanoscale. People, Policies and Emerging Technologies*, London: DEMOS.

**Kezar**, A. (2003) 'Transformational Elite Interviews. Principles and Problems', *Qualitative Inquiry* **9**(3) 395–415.

**Kivinen**, O., Varelius, J. (2003) 'The Emerging Field of Biotechnology. The Case of Finland', *Science, Technology & Human Values* **28**(1) (Winter 2003) 141–161.

**Konopásek**, Z., Stöckelová, T., Zamykalová, L. (2008) 'Making Pure Science and Pure Politics. On the Expertise of Bypass and the Bypass of Expertise', *Science, Technology & Human Values* **33**(4) 529–553.

**Kretschmer**, T. *et al* (2005) *Nanotechnologie. Grundlagen und Anwendung*, Stuttgart: Fraunhofer IRB Verlag.

**Kuhn**, T.S. (1993) *Die Struktur Wissenschaftlicher Revolutionen*, Frankfurt/Main: Suhrkamp.

**Kurzweil**, R. (1990) *The Age of Intelligent Machines*, Cambridge/MA: MIT Press.

**Latour**, B., Woolgar, S. (1986) *Laboratory Life. The Construction of Scientific Facts* (2nd edition), Princeton: Princeton University Press.

**Latour**, B. (2000) *Die Hoffnung der Pandora. Untersuchungen zur Wirklichkeit der*

*Wissenschaft*, Frankfurt/Main: Suhrkamp.

**Lincoln**, Y.S., Guba, E.G. (2000) 'The Only Generalization is There is no Generalization', in: Gomm, R., Hammersley, M., Foster, P. (eds) *Case Study Method. Key Issues, Key Texts*, London; Thousand Oaks: SAGE, 27–44.

**Łojek-Osiejuk**, E. (1996) Knowledge of Scripts Reflected in Discourse of Aphasics and Right-Brain-Damaged Patients, *Brain and Language* **53**, 58–80.

**Lopez**, J. (2004) 'Bridging the Gaps. Science Fiction in Nanotechnology', *International Journal for Philosophy of Chemistry* **10**(2) 129–152.

**Macdonald**, K. (2001) 'Using Documents', in: Gilbert, N. (ed) *Researching Social Life* (2nd edition), London: SAGE, 194–210.

**Marcum**, J.A. (2008) 'Does Systems Biology Represent a Kuhnian Paradigm Shift?', *New Phytologist* **179**(3) 587–589.

**Marris**, C. (2001) 'Public Views on GMOs. Deconstructing the Myths', *EMBO Reports* **2**(7) 545–548.

**Martin**, M., Gruetzmacher, R.R., Lanham, R., Brady, J. (2004) 'Assessing Technology Transfer and Business Development Potential. Technology Cluster Analysis', *Economic Development Quarterly* **18**(2) 168–173.

**Mason**, J. (2004) 'Personal Narratives, Relational Selves. Residential Histories in the Living and Telling', *The Sociological Review* **52**(2) 162–179.

**May**, T. (2001) *Social Research. Issues, Methods and Process* (3rd edition), Buckingham; Philadelphia/PA: Open University Press.

**McLaughlin**, J., Goodley, D. (2008) 'Seeking and Rejecting Certainty. Exposing the Sophisticated Lifeworlds of Parents of Disabled Babies', *Sociology* **42**(2) 317–335.

**Meht**a, M.D. (2002) 'Nanoscience and Nanotechnology. Assessing the Nature of Innovation in These Fields', *Bulletin of Science, Technology & Society* **22**(4) 269–273.

**Mehta**, M.D. (2004) 'From Biotechnology to Nanotechnology. What Can We Learn From Earlier Technologies?', *Bulletin of Science, Technology & Society* **24**(1) (February 2004) 34–39.

**Meridian Institute** (ed) (2004) *International Dialogue on Responsible Research and Development of Nanotechnology*, Alexandria/VA: Meridian Institute.

**Milburn**, C. (2002) 'Nanotechnology in the Age of Posthuman Engineering. Science Fiction as Science', *Configurations* **10**, 261–295.

**Mnyusiwalla**, A., Daar, A.S., Singer, P.A. (2003) ''Mind the Gap'. Science and Ethics in Nanotechnology', *Nanotechnology* **14** (R9–R13).

**Mody**, C.C.M. (2004) 'Small but Determined. Technological Determinism in Nanoscience', *International Journal for Philosophy of Chemistry* **10**(2) 99–128.

**Moriarty**, P. (2008) 'Reclaiming Academia from Post-Academia', *Nature Nanotechnology* **3** (February 2008) 1–3.

**Morillo**, F., Bordons, M., Gómez, I. (2003) 'Interdisciplinarity in Science. A Tentative Typology of Disciplines and Research Areas', *Journal of the American Society for Information Science and Technology* **54**(13) 1237–1249.

**Newton**, D.E. (2002) *Recent Advances and Issues in Molecular Nanotechnology* (Frontiers of Science Series), Westport/CT: Greenwood Press.

**Niemeyer**, C.M., Mirkin, C.A. (eds) (2004) *Nanobiotechnology. Concepts, Applications, Perspectives*, Weinheim: Wiley-VCH.

**Nordmann**, A. (2004) 'Molecular Disjunctions. Staking Claims at the Nanoscale', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 51–62.

**Nowotny**, H., Scott, P., Gibbons, M. (2001) *Re-Thinking Science. Knowledge and the Public in an Age of Uncertainty*, Cambridge: Polity Press.

**Oksaar**, E. (1988) *Kulturemtheorie. Ein Beitrag zur Sprachverwendungsforschung*, Göttingen: Vandenhoek & Ruprecht.

**O'Mally**, M.A., Calvert, J., Dupré, J. (2007) 'The Study of Socioethical Issues in Systems Biology', *The American Journal of Bioethics* **7**(4) 67–78.

**Osbourne**, T. (2002) 'History, Theory, Disciplinarity', in: Joyce, P. (ed) *The Social in Question. New Bearings in History and the Social Sciences*, London; New York: Routledge, 175–190.

**Packer**, K., Webster, A. (1996) 'Patenting Culture in Science. Reinventing the Scientific Wheel of Credibility', *Science, Technology & Human Values* **21**(4) 427–453.

**Pidgeon**, N. (2004) 'Shaping Public Attitudes and Awareness', in: Is Nanotechnology the Next GM? (Economic and Social Research Council) *The Edge* **16** (June 2004).

**Pidgeon**, N., Rogers-Hayden, T. (2007) 'Opening up Nanotechnology Dialogue with the Publics. Risk Communication or 'Upstream Engagement'?', *Health, Risk & Society* **9**(2) 191 – 210.

**Pilarski**, L.M. *et al* (2004) 'Microsystems and Nanoscience for Biomedical Applications. A View to the Future', *Bulletin of Science, Technology & Society* **24**(1) 40–45.

**Polenske**, K.R. (2004) 'Competition, Collaboration and Cooperation. An Uneasy Triangle in Networks of Firms and Regions', *Regional Studies* **38**(9) 1029–1043.

**Ponterotto**, J.G., Grieger, I. (1999) 'Merging Qualitative and Quantitative Perspectives in a Research Identity', in: Kopala, M., Suzuki, L. (eds) *Using Qualitative Methods in Psychology*, London; Thousand Oaks: SAGE, 49–62.

**Redden**, G. (2002) 'The New Agents. Personal Transfiguration and Radical Privatization in New Age Self-Help', *Journal of Consumer Culture* **2**(1) 33–52.

**Rehmann-Sutter**, Ch. (n.d.) *Ethical Implications of Nanosciences. A Provisional Inventory and Some Methodological Reflections* (unpublished paper).

**Rehmann-Sutter**, Ch., Leach Scully, J. (forthcoming) 'Which Ethics for (of) the Nanotechnologies?', in: Maasen, S., Kaiser, M. (eds) *Assessment Regimes of Technology. Regulation, Deliberation & Identity Politics of Nanotechnology* (Sociology of the Sciences Yearbook, Vol. 27), Dordrecht: Springer.

**Rey**, L. (2003) *Cutting Nature's Building Blocks Down to Size* (Abridged Version of the TA-SWISS Study "Nanotechnology in Medicine"), Bern: TA-SWISS, 25–36.

**Rip**, A. (2000) 'Fashions, Lock-ins and the Heterogeneity of Knowledge Production', in: Jacob, M., Hellström, T. (eds) *The Future of Knowledge Production in the Academy*, Buckingham: SRHE & Open University Press, 28–39.

**Rip**, A. (2002) *A Co-Evolutionary Perspective on ELSI, CTA and Other Attempts at Re-Contextualisation of Science and Technology in Society* (paper for EASST Conference, York, August 2002).

**Rip**, A. (2005) *Technology Assessment as Part of the Co-Evolution of Nanotechnology and Society. The Thrust of the TA Program in NanoNed* (paper contributed to the conference on "Nanotechnology in Science, Economy and Society", Marburg, 13-15 January 2005).

**Robinson**, W.L. (2004) 'Nano-Ethics', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 285–300.

**Roco**, M.C., Sims Bainbridge, W. (eds) (2001) *Societal Implications of Nanoscience and Nanotechnology*, Dordrecht: Kluwer.

**Roukes**, M.L. (2002), 'Foreword' and 'Plenty of Room, Indeed', in: Fritz, S. (ed) *Understanding Nanotechnology* (by the editors of the Scientific American), New York; Boston: Time Warner Book Group.

**Roulsten**, K., deMarrais, K., Lewis, J.B. (2003) 'Learning to Interview in the Social Sciences', *Qualitative Inquiry* **9**(4) 643–668.

**Ryan**, J. (2004) 'Let's Not Miss Out on the Next Industrial Revolution', in: Is Nanotechnology the Next GM? (Economic and Social Research Council), *The Edge* **16** (June

2004).

**Salata**, O.V. (2004) 'Applications of Nanoparticles in Biology and Medicine', *Journal of Nanobiotechnology* **2**(3).

**Sandler**, R., Kay, W.D. (2006) 'The GMO-Nanotech (Dis)Analogy?', *Bulletin of Science, Technology and Society* **26**(1) 57–62.

**Scheufele**, D.A. *et al* (2007) 'Scientists Worry About Some Risks More Than the Public' (commentary), *Nature Nanotechnology* (November 2007) 2–4.

**Schmidt**, J.C. (2004) 'Unbounded Technologies. Working Through the Technological Reductionism of Nanotechnology', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 35–50.

**Schot**, J., Rip, A. **(**1997) 'The Past and Future of Constructive Technology Assessment', *Technological Forecasting and Social Change* **54**, 251–268.

**Schummer**, J. (2004a) 'Interdisciplinary Issues in Nanoscale Research', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 9–20.

**Schummer**, J. (2004b) 'Multidisciplinarity, Interdisciplinarity, and Patterns of Research Collaboration in Nanoscience and Nanotechnology', *Scientometrics* **59**(3) 425–465.

**Schummer**, J. (2004c) 'Societal and Ethical Implications of Nanotechnology. Meanings, Interest Groups, and Social Dynamics', *Techné: Research in Philosophy and Technology* **8**(2) 54–87.

**Schwarz**, A.E. (2004) 'Shrinking the Ecological Footprint with NanoTechnoScience?', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 203–208.

**Shea**, C.M. (2005) 'Future Management Research Directions in Nanotechnology. A Case Study', *Journal of Engineering and Technology Management* **22**, 185–200.

**Silverman**, D. (2005) *Doing Qualitative Research. A Practical Handbook* (2nd edition), London: SAGE.

**Silverman**, D. (2006) *Interpreting Qualitative Data. Methods for Analyzing Talk, Text and Interaction* (3rd edition), London: SAGE.

**Simmel**, G. (2007) 'The Social Boundary', *Theory Culture & Society* **24**(7-8) 53–56.

**Sims Bainbridge**, W. (2004) 'Social and Ethical Implications', in: Bhushan, B. (ed) *Springer Handbook of Nanotechnology*, Berlin; New York: Springer, 1135–1149.

**Smalley**, R.E. (2001) 'Of Chemistry, Love and Nanobots', *Scientific American*, **285**(3) (September) 76–77.

**Smith**, K.E. (2006) 'Problematising Power Relations in 'Elite' Interviews', *Geoforum* **37**(4) 643–653.

**Soloviev**, M. (2007) 'Nanobiotechnology Today. Focus on Nanoparticles', *Journal of Nanobiotechnology* **5**(11).

**Stake**, R.E. (2000) 'The Case Study Method in Social Inquiry', in: Gomm, R., Hammersley, M., Foster, P. (eds) *Case Study Method. Key Issues, Key Texts*, London; Thousand Oaks: SAGE, 19–26.

**Star**, S.L. (1988) 'Introduction. The Sociology of Science and Technology', *Social Problems* **35**(3) (June 1988) 197–205.

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

**Stilgoe**, J. (2007) *Nanodialogues. Experiments in Public Engagement with Science*, London: DEMOS.

**Stix**, G. (2001) 'Little Big Science', in: Fritz, S. (ed) (2002) *Understanding* Nanotechnology (by the editors of the Scientific American), New York: Time Warner Book Group.

**Stoneqvist**, E.V. (1935) 'The Problem of the Marginal Man', *The American Journal of Sociology* **41**(1) 1–12.

**Strathern**, M. (2004) *Commons and Borderlands. Working Papers on Interdisciplinarity, Accountability and the Flow of Knowledge*, Wantage: Sean Kingston.

**Strathern**, M. (2006) 'Knowledge on its Travels. Dispersal and Divergence in the Makeup of Communities', *Interdisciplinary Science Reviews* 31(2) 149–162.

**The Action Group on Erosion, Technology and Concentration** (ETC Group) (2003) *The Big Down. From Genomes to Atoms*, Winnipeg/Canada: ETC Group.

**The European Parliament and the Council** (2006) *Decision No. 1982/2006/EC (18 December 2006) concerning the Seventh Framework Programme of the European Community for Research, Technological Development and Demonstration Activities (2007-2013)*, European Union.

**The Royal Society & The Royal Academy of Engineering** (2004) *Nanoscience and Nanotechnologies. Opportunities and Uncertainties*, London: The Royal Society & The Royal Academy of Engineering.

**Toumey**, C. (2004) 'Narratives for Nanotech. Anticipating Public Reactions to

Nanotechnology', *Techné: Research in Philosophy and Technology* **8**(2) 88–116.

**Van den Belt**, H., Rip, A. (1987) 'The Nelson-Winter-Dosi Model and Synthetic Dye Chemistry', in: Bijker, W.E., Hughes, T.P., Pinch, T.J. (eds) *The Social Construction of Technological Systems. New Directions in the Sociology and History of Technology*, Cambridge/MA: MIT Press, 135–158.

**Vanderburg**, W.H. (2006) 'Can the University Escape From the Labyrinth of Technology? Part 2: Intellectual Map-Making and the Tension Between Breadth and Depth', *Bulletin of Science, Technology & Society* **26**(3) 178–188.

**Verganti**, Roberto (1999) 'Planned Flexibility. Linking Anticipation and Reaction in Product Development Projects', *Journal of Product Innovation Management* **16**(4) 363–376.

**Vermaas**, P.E. (2004) 'Nanoscale Technology. A Two-Sided Challenge for Interpretations of Quantum Mechanics', in: Baird, D., Nordmann, A., Schummer, J. (eds) *Discovering the Nanoscale*, Amsterdam: IOS Press, 77–91.

**Wagner**, C.S., Leydesdorff, L. (2005) 'Network Structure, Self-Organization, and the Growth of International Collaboration in Science', *Research Policy* **34**, 1608–1618.

**Warde**, A., Bennett, T. (2008) 'A Culture in Common. The Cultural Consumption of the UK Managerial Elite', *Sociological Review* **56**(1) (May 2008) 240–259.

**Webster**, A. (1994) 'University-Corporate Ties and the Construction of Research Agendas', *Sociology* **28**(1) 123–142.

**Webster**, A. (2007a) *Health, Technology and Society. A Sociological Critique*, Basingstoke: Palgrave Macmillian.

**Webster**, A. (2007b) 'Crossing Boundaries. Social Science in the Policy Room', *Science, Technology & Human Values* **32**(4) 458–478.

**Whitesides** G.M., Mathias J.P., Seto, C.T. (1991) 'Molecular Self-Assembly and Nanochemistry. A Chemical Strategy for the Synthesis of Nanostructures', *Science* **254**, 1312–1319.

**Whitesides**, G.M. (2001) 'The Once and Future Nanomachine. Biology Outmatches Futurists' Most Elaborate Fantasies for Molecular Robots', *Scientific American* **285**(3) 78–83.

**Whitesides**, G.M., J.C. Love (2001) 'Implications of Nanoscience for Knowledge and Understanding', in: Roco, M.C., Sims Bainbridge, W. (eds) *Societal Implications of Nanoscience and Nanotechnology*, Kluwer: Dordrecht, 129–144.

**Wienroth**, M. (forthcoming) 'Disciplinarity and Research Identity in Nanoscale Science and Technologies', in: Ach, J.S., Weidemann, Ch. (eds) *Size Matters. Ethical, Legal and Social Aspects of Nanobiotechnology and Nano-Medicine* (Münsteraner Bioethik-

Studien, Vol.8), Münster: Lit.

**Williams**, R., Edge, D. (1996) 'The Social Shaping of Technology', *Research Policy* **25**, 856–899.

**Williams**, R. (2000) *Making Identity Matter. Identity, Society and Social Interaction*, York: Sociologypress.

**Williams**, R.S., P.J. Kuekes (2001) 'We’ve Only Just Begun', in: Roco, M.C., Sims Bainbridge, W. (eds) *Societal Implications of Nanoscience and Nanotechnology*, Dordrecht: Kluwer, 103–107.

**Wood**, S., Jones, R., Geldart, A. (2003) *The Social and Economic Challenges of Nanotechnology*, Swindon: Economic and Social Research Council.

**Woolgar**, S. (1988) *Science. The Very Idea*, London: Tavistock.

**Wynne**, B. (2004) 'Learning the Real Lessons from GM', in: Is Nanotechnology the Next GM? (Economic and Social Research Council) *The Edge* **16** (June 2004).

**Zhao**, Y., Zhang, X. (2007) 'Nanobiotechnology. An Engineer's Foray into Biology', *Advances in Computers* **71**, 39–102.

## Online Sources


**Bremer Institut für Kunst Musik Design Wissenschaft** (Bremen Institute for Art Music Design Science) <http://www.institut-syn.de>, viewed on 7 August 2007.

**Center for Responsible Nanotechnology**, <http://www.crnano.org/whatis.htm>, viewed on 11.02.2006.

**Cranfield University**, **UK**, <http://www.cranfield.ac.uk/sims/staff/ramsdenj.htm>, viewed on 16.02.2006.

**Feynman**, R. P. (n.d.) *There's Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics*, <http://www.zyvex.com/nanotech/feynman.html>, viewed on 21.02.2006.

**Flinders University**, **Adelaide, Australia**, BSc in Nanotechnology, <http://www.scieng.flinders.edu.au/courses/ nanotechnology>, viewed on 16.02.2006.

**Hogue,** T. (1993) *Community-Based Collaboration: Community Wellness Multiplied, Chandler Center for Community Leadership*, <http://crs.uvm.edu/nnco/collab/wellness.html>, viewed on 03.10.2006

**Homepage of Eric Drexler**, <http://e-drexler.com>, viewed on 22.02.2006.

**Institute for Nanoscale Science and Technology**, <http://www.ncl.ac.uk/insat>, viewed on 13.02.2006.

**Institute for Nanotechnology Exploitation**, <http://www.inex.org.uk>, viewed on 09.01.2006. (since 2007: INEX).

**Jacob**, P. (2003) *A philosopher's reflections on his interactions with a neuroscientist, CNRS symposium on Re-Thinking Interdisciplinarity*, <http://www.interdisciplines.org/ interdisciplinarity/papers/4>, viewed on 18.01.2006.

**Mansilla**, V.B., Gardner, H. (2003) 'Assessing Interdisciplinary Work at the Frontier. An Empirical Exploration of 'Symptoms of Quality'', *CNRS symposium on Re-Thinking Interdisciplinarity*, <http://www.interdisciplines.org/interdisciplinarity/papers/6>, viewed on 18.01.2006.

**Merriam-Webster's Collegiate Dictionary**, <http://www.m-w.com/dictionary/ nanotechnology>, viewed on 22.02.2006.

**Nowotny**, H. (2003) 'The Potential of Transdisciplinarity', *CNRS symposium on Re-Thinking Interdisciplinarity*, <http://www.interdisciplinarity.org/interdisciplinarity/papers/5>, viewed on 18.01.2006

**Pestre**, D. (2003) 'The Evolution of Knowledge Domains. Interdisciplinarity and Core Knowledge', *CNRS symposium on Re-Thinking Interdisciplinarity*, <http://www.inter disciplines.org/interdisciplinarity/papers/8>, viewed on 18.01.2006.

**Rögener**, W. (2006) 'Krieg im Zwergenreich: Künstliche Muskeln, die stark machen. Chamäleon-Fahrzeuge, die unsichtbar machen. Anzüge, die unverwundbar machen. Die Armee der Zukunft könnte ein Science-Fiction-Autor entsonnen haben', S*ueddeutsche Online*, 21.02.2006. (newspaper article)

**Siegel**, R.W., Hu, E., Roco, M.C. (eds) (1999) *Nanostructure Science and Technology. A Worldwide Study*, National Science and Technology Council (USA), <http://www.wtec.org/ loyola/nano/>, viewed on 15.04.2008.

**Universität Basel**, **Switzerland**, BSc / MSc courses in Nanosciences, <http://www.unibas.ch/index.cfm>, viewed on 02.03.2006.

**Universität des Saarlandes**, **Germany**, Diplom-Physiker / Diplom-Ingenieur in Micro- and Nanostructures, <http://www.uni-saarland.de/de/studium/studienangebot/ mikro_nano_strukturen/>, viewed on 02.03.2006.

**University of Washington**, **Seattle, USA**, PhD course in Nanotechnology, <http://www.nano.washington.edu/education/proginfo.html>, viewed on 16.02.2006.

**University of York**, **UK**, Bachelor / Master courses of Electronic Engineering with Nanotechnology, <http://www.elec.york.ac.uk/ugrad/course/nanotechnology.htm>, viewed on 16.02.2006.

**Woodrow Wilson International Center for Scholars**, <www.nanotechproject.org>, viewed on 23.07.2008.

**Zimmerli**, W.Ch. (2008) 'Welche Technik bringt uns weiter?', *Zeit Online*, viewed on 08.01.2008. (newspaper article)

# Appendices

# Appendix 1

**Aide Mémoire – First Draft**

A. Professional background

1. Job title and description

2. What is your current place of work?
   duration of stay

3. Educational background
   qualifications research interests
   years of experience research areas

4. How would you characterise the area/ the discipline in which you are working?
   'mother' discipline? specialisation
   How do other people see your vocation?

B. Research experiences

5. Is your current work place involved in nanotechnology or nanoscience?
   How? How do you understand these concepts?

6. Do you relate your work to NST?
   Identification/association?
   Do you follow events/debates?

7. How do you inform yourself of other projects / developments in your field of work?

8. Please describe other aspects of your current work, your everyday experiences.
   kind of projects tasks in research
   basic/applied research

C. Experiences with collaboration in NST

9. Are you involved in projects where project members come from different disciplinary backgrounds?
   natural + clinical scientists, social scientists and ethicists, policy-makers
   Do you know all participants? Specific background known?
   Issues of collaboration? Advantages from collaboration?
   motives for collaboration

10. Are you part of the same organisational framework?
    sharing administrative structures
    decision-making processes/autonomy
    common goals/project aims

11. Do you meet / share workplaces with project colleagues?
    With whom? physical proximity

Shared workplace practices, discussion meetings, briefings, reviews?

12. Is there a format for organising introduced/incorporated knowledge in your research/project?

13. What discipline are colleagues from that you work more often with?

14. Do you share any kind of research activities [methods, results, opinions]?

15. What are your experiences when talking with colleagues about the project or your part of the project?
    regarding understanding of technology, concepts, methods, project aims etc.
    difficulties and attempts to solve those?
    How much time do you spend on explaining and negotiating?

16. Is there any impact of working with colleagues from other backgrounds on
    a) your understanding of the project
    b) its aims
    c) on your field of expertise?

17. In your opinion, is there anything distinct about researching at Newcastle University, in Newcastle?
    research support/focus
    institutional reasons

D. Future developments

18. Do you think your disciplinary understanding of yourself as a researcher changes over time?

19. Do you consider future collaboration with researchers from other backgrounds?

20. Is participating in a declared nanotechnology project an option for you?

21. How should junior researchers be trained in/for NST?

22. What does NST mean to you?

# Appendix 2

| Revised Aide Mémoire |
|---|
| Sections and Main Questions (February 2007) |

| Disciplinary Background | NST Connectivity | NST Collaboration |
|---|---|---|
| Job description | Defining of NST | Kind of coll. project work |
| Professional training | Workplace affiliation? | Administration of coll. |
| Research interests | Research affiliation? | Collaborative activities |
| Research area(s)/field(s) | NST debates (scientific and public) | Motivations for collaboration |
| Research tasks | | Impact of collaboration |

# Appendix 3

## Participant Information Sheet

Thank you for considering participating in my research.

Our talk today is part of my on-going PhD-project, in which I explore scientists and engineers' understanding of nanoscale science and technology, and how research in this area is experienced. The project focuses on how collaboration takes place, and how researchers relate to nanoscale science and technology. I am conducting interviews with academic researchers from Newcastle upon Tyne.

I would like to assure you that (1) all information/data disclosed during our interview will be treated confidentially, (2) all personal data will be made anonymous, and (3) every effort will be made to retain your anonymity during presentations and publications in as far as this case study of academic research in Newcastle allows.

The digital record of our interview will be digitally encrypted and stored in a safe place. The file name will feature a code that does not refer to your name or institution. During the process of transcription only I shall have access to the full interview content.

The information from our interview will be treated confidentially, this means there will be no discussion of your identity with anyone except my two supervisors. On transcription, the interview content will be made anonymous by excluding details such as your name, your full job title and the name of the specific projects/institutions that you are affiliated with. However, as this is a case study of possible interdisciplinarity, interviewees will be referred to by disciplinary affiliation/identification in the analysis, presentations and publications.

Should you require it, a transcript of our interview can be made available to you in due course.

Thank you.

# Appendix 4

## Interview Consent Form

Interview Consent Form

Thank you for agreeing to participate in this interview. This form serves as assurance (1) that the content of the interview will be treated confidentially, and (2) that personal data will be anonymised as far as possible.

Safety, Confidentiality and Anonymity of Interview Content

The digital record-file containing the interview content will be digitally encrypted and stored in a safe place. The file name will feature a code not referential to your name and institution, and the code key will be kept apart from the file. During the process of transcription only the interviewer will have access to the full interview content, and information will be made anonymous as exemplified below for the use thereafter in analysis, presentations and publications.

The content from the interview will be treated confidentially, i.e. there will be no discussion of possible identities with anyone except the supervisory team (who might have recommended contacting the respondent). The interview content will be anonymised by excluding name, full job title/research role and the name of the specific project/institution that the respondent is affiliated with. As this is a case study of Newcastle academic research, 'institution' signifies the School or Research Institute/Centre, not the University or Faculty. The disciplinary affiliation/identification, which the respondent has indicated, will still be required to be given in analysis, presentations and publications due to the nature of the project (disciplinarity aspect).

The anonymised data from the recorded interview might be used

- ☐ in analysis (PhD thesis)
- ☐ in forum presentations (seminars, conferences)
- ☐ in publications.

By signing the form, consent will be given to the use of data under the conditions exemplified above. Thank you.

__________ ____________________________

Date Signature (respondent)