Supersizing Science

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On Building Large-Scale Research Projects in Biology

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The illustration on the cover, 'Spiral IV', is made by Kenneth Eward. I am grateful for his permission to use his work which stayed with me after I first saw it in the Science Visualization Challenge 2004, where it received an honourable mention:

> If you could climb the twisted ladder of a DNA molecule and look down, you might see something like the image above. Kenneth Eward, a science artist at BioGrafx Scientific & Medical Images in Ovid, Michigan, used x-ray crystallographic data from DNA molecules to paint a unique portrait of the double helix. The image omits the chemical bonds that crisscross the center of the molecule, so that the structural features of the helix can be seen more easily. (Grimm, 2004: 1905)

To me 'Spiral IV' does not only picture a vital part of modern biology, but it also represents the process of growing bigger. This idea, in turn, formed the basis for the cover design. I want to thank Jan van Beusekom for giving this Vermeulen book its cover.

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Acknowledgements

Writing a book about scientific collaboration on your own may seem to be a mission impossible. Luckily, I did not have to do it alone. Although this book is the result of my personal research endeavour, I would like to acknowledge the support I received from many around me. First of all, I want to thank my supervisors Wiebe Bijker and Rein de Wilde. By showing me the delights of research Rein inspired me to engage in this study and Wiebe can be best described as my academic guide. You have given me full freedom to develop my own project, which has been a genuine learning experience. My fellowship at the University of York gave me a third person who has been vital. I want to express my sincere gratitude to Andrew Webster and all the other people at York who provided me with an academic home abroad. In addition, I am thankful for the support of my fellow PhD's and other colleagues from the Faculty of Arts and Social Sciences, the Netherlands Graduate Research School of Science, Technology and Modern Culture (WTMC), the European Association for the Study of Science and Technology (EASST), and the Society for Social Studies of Science (4S). Of course, I am especially grateful for the cooperation of the life scientists and policymakers who figure as key players in the subject of this study. Over the years I was fortunate to meet other scholars who investigate and explore scientific collaboration, and I am certainly looking forward to our future collaboration. Several persons I met during my research have meanwhile become good friends and are now part of the group of people who accompany me through life. My dear friends, let me assure you: your friendship is bigger than big! Finally, I would like to thank my close relatives who have been with me from the very beginning with love. Mam en Floor: samen staan we sterk!

Introduction

Nobel Prize winners James Watson and John Sulston both wrote memories of their contribution to molecular biology, respectively the reconstruction of the structure of Deoxyribose Nucleic Acid (DNA) in 1953 and the development and realisation of the Human Genome Project about fifty years later (Watson, 1968; Sulston & Ferry, 2002). Together, these books comprise an overview of major developments in the life sciences during the last century. At the same time a comparison of the two stories shows several striking differences. Watson tells about the scientific quest of a small group of scientists who pursue their research in a relatively small-scale academic environment. Informed by the work of others, Watson and Crick developed their model in the Cavendish Laboratory in Cambridge, the traditional English university town. Although Sulston's career began in the same academic setting – working on the genetic make-up of worms at the Laboratory of Molecular Biology – his story on the development of the Human Genome Project describes a completely different world. The deciphering of the human genome entails the planning and management of a large and dynamic project with a clear mission, involving huge amounts of money, expensive instruments and numerous scientists in laboratories all over the world. Moreover, the academic environment is substituted by an international and political setting, figuring academia, governments, funding bodies, business, media and the public.

What makes these two research endeavours in biology so different? How is it possible that Watson and Sulston are portraying such diverse pictures of a life devoted to science? The two stories indicate the emergence of a new way of doing research in biology. A central feature of the transformations in contemporary life sciences research is the movement towards more collaboration. While Watson and Crick worked together and only sometimes discussed their work with other scientists, the Human Genome Project connected forty-eight laboratories and involved more than five hundred scientists (Glasner, 2002). Moreover, the Genome project has been followed by various comparable large-scale research projects in biology (Eichinger, 2007; Glasner, 1996; Glasner, 2002; Editorial Nature, 2001). It is this transformation in the orchestration of contemporary life sciences research that I investigate in my thesis. I explore how in biology scientific and technological developments interact with organisational changes towards an increase in collaboration. I show how these collaborations are built and characterise scientific collaboration in biology.

My investigations into scientific collaboration in biology have to be understood in the context of studies on 'big science' and scientific collaboration in general. Interest in increasing dimensions of science began in the 1960s, when the term 'big science' was introduced (Price, 1963; Weinberg, 1967). Nowadays, science increasingly has become a collaborative effort, while also more and more studies of scientific collaboration have appeared (Hackett, 2005; Katz & Martin, 1997; Shrum et al., 2007). However, these old and new studies predominantly address disciplines that are known to have a tradition in collaboration, like astronomy, physics and space research. In contrast, I turn the spotlight on biology. Moreover, in the context of biology my thesis specifically focuses on the building of large-scale research projects in contemporary society. What kind of work has to be done to build collaboration? Adapting the notion of big science, I call this process of science becoming bigger the 'supersizing of science'.

Why is the supersizing of science and, more specifically, collaboration in biology worth investigating? Knowledge plays an important role in modern society and recent developments in the life sciences have a profound influence on diverse societal realms. As the desire to acquire knowledge, including knowledge about life, seems inherent to being human, research into life and its diversity has been fundamental in the development of modern science and the scientific profession (Pickstone, 2000). Nowadays, science has become a crucial component of society, with science being constitutive of many social processes, while it is almost impossible to think of society without taking the role of science into account (De Wilde, 2001; Jasanoff et al., 1995). More particularly, increasing knowledge about life at the molecular level has an enormous impact on agriculture, healthcare and industrial processes (Brown & Webster, 2004; Vermeulen, 2003; WRR, 2003). Think for example of genetically modified organisms, the development of genetic diagnosis and therapy, the use of biomaterials and bioenergy. Forensic research nowadays involves the examination of DNA as 'genetic fingerprints' (Butler, 2005).

Understanding science and the role of science in society, is the objective of a relatively new academic field that is known as the social studies of science, or

– including the role of technology – Science and Technology Studies (STS). Having its roots in the history, philosophy and sociology of science, this interdisciplinary community of scholars studies the interaction between science, technology and society, finding that they are co-shaping in various ways (Jasanoff et al., 1995; Hackett et al., 2008; Sismondo, 2004). My thesis is written within this academic context, and I concentrate especially on the organisation of science. Social studies of science have shown that the organisation of research plays an important role in the creation of knowledge (Jasanoff et al., 1995; Knorr-Cetina, 1999; Latour, 1987; Vaughan, 1999). As a result, the building of collaboration in biology comprises a development that is worth reflecting on as it influences the construction of knowledge and is part of the supersizing of science.

How to study collaboration in biology?

One of the central insights from science studies holds that science has two faces: science in the making and ready-made science (Latour, 1987). Research – science in the making – is not an orderly process, which is planned at the beginning and followed by some logical actions that automatically lead to specific results. Often, it is only afterwards that science is presented as an orderly process: ready-made science. These insights into the ways in which science is made also poses a dilemma to the science studies scholar wanting to describe her own research process. Which road to take? Present ready-made science, or show science in the making? It will come as no surprise that to some extent my research process has been messy too. However, looking back it is possible to impose a certain sense of order on the processes involved. In this introduction I will recount both stories in a nutshell: first I will show some of the mess, after which I will explain how I managed to order it.

Beginning with the mess, let me tell about the origins of my research. This dissertation has its roots in Washington D.C., where I studied life sciences innovation policies for the Scientific Council at the Royal Netherlands Embassy. I found myself at the right place at the right time as it was the year 2003, marking the 50th anniversary of the publication of the structure of DNA by Watson and Crick together with the official completion of the Human Genome Project. To celebrate, lots of different activities related to the life sciences were organised. Most importantly the scientific symposium 'From Double Helix to Human Sequence – and beyond' at the National Institutes of Health, in which main actors in these developments, including Watson and Crick, told their stories about biology in past, present and future. This meeting was accompanied by a public symposium at the Natural History Museum and an exhibition on DNA. Moreover, there were policy oriented meetings on the Hill and the large annual BIO convention organised by the life sciences industry bringing together 16,234 participants from fifty-seven countries.[1]

In between attending these meetings and looking at science and innovation policies in the United States, I started wondering about this world of life sciences I was temporarily emerged in. Having a background in Science and Technology Studies, I recognised transformations that are described in recent literature on science and innovation. Like the emergence of what is called a new mode of knowledge production – the trans-disciplinary 'mode 2' research that takes place in the context of application – and the entanglement of academia, government and industry in the so-called 'triple-helix' (Gibbons et al., 1994; Etzkowitz & Leydesdorff, 2000; Nowotny, et al., 2001). However, what struck me most was the relative lack of attention to what all these changes meant for the actual research practice and the life of individual scientists. This made me decide that I wanted to look at contemporary transformations in the life sciences, focussing on the perspective of science and scientists.

Although my work can be best characterised as science studies, I did not perform ethnographic study of laboratory work, following scientists and describing their actions (Doing, 2007; Latour & Woolgar, 1986). Nor did I focus primarily on the analysis of science policy (Bucchi, 2004; Guston, 2000; Jasanoff, et al., 1995). Instead, I tried to find a place in between, where scientific practice and the organisation of science meet each other. In other words, I moved my study of science outside the laboratory into the space between laboratory practice and science policy. It is in this space that scientific collaboration is formed, entailing both scientific and organisational developments. Moreover, it is in this space outside the laboratory, where scientists are most clearly involved in and confronted with the contemporary societal attention to developments in biology, and the increasing entanglement of academia with government and industry. Finally, I pay explicit attention to the role of technology in science and the organisation of science, as scientific and technological developments go hand in hand in biology and other sciences that are characterised as 'techno-science' (Pickstone, 1993; Gibbons et al., 1994).

When doing laboratory studies, the sites of study are quite clear. But given that I decided to move outside of the laboratory, where, exactly, should my effort be situated? In fact, my empirical research took place at a variety of sites.[2]

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[1] Number of attendees of BIO 2003 retrieved January 22, 2008 from www.bio.org/events/-2003/media/facts.asp

[2] Within anthropology this form of fieldwork is referred to as 'multi-sited ethnography' (Müller-Rockstroh, 2007).

First of all, I went to meetings, where scientists and other actors in the life sciences field meet. I visited scientific conferences, workshops, policy meetings, business events and network meetings and became involved in various networks of young scientists. Here I observed and – most importantly – talked to scientists and other actors actively involved in the world of life sciences, such as policymakers and businessman.[3] More specifically, I conducted in-depth interviews with a selection of those people, talking about their work and perspectives on developments in the life sciences, transformation in scientific practice and the role of scientists.[4] Secondly, I decided to concentrate on large-scale scientific collaborations in biology, because within these projects transformations in biology come together and materialise.[5] Moreover, these projects influence daily scientific practice and the professional life of scientists. I studied three different scientific collaborations in detail, analysing project and policy documents and talking to key scientists in the project, as well as to persons involved in the organisation or policies associated with the projects.

The projects I have chosen to study are all examples of contemporary scientific collaborations that investigate life, but in order to get an idea of both similarities and differences the three case studies represent diverse forms of research collaborations with different goals, varying from making an inventory, to transforming or applying information. First, the Census of Marine Life aims to study all animal life in the world's oceans and collect them in a virtual database. Second, the Silicon Cell initiative aims to build a model of a cell in a computer, synthesizing different data that have become known of various components of cells, including genetic information. Third, the VIRGO consortium is an academic-industrial collaboration that uses genomics techniques to develop new therapies against respiratory virus infections, such as influenza, and explicitly aims to apply knowledge that is acquired through research. I studied the various collaborations from their beginning until 2007, when I completed my empirical work.

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[3] For an overview of attended meetings see Appendix A.

[4] For an overview of interviews see Appendix B. The quotes from Dutch interviews are translated into English by the author of this thesis.

[5] Scientific collaboration can have various forms (on definitions of collaboration, see Chapter 1 and the report of the 'Workshop Research Groups and Science Collaboration' by Braam & Verbree, 2008). I have chosen to concentrate on large-scale research projects, involving various national or international partners that present themselves as a research project and receive or aim to receive separate funding for this specific research project.

Presenting scientific collaboration in biology

In this thesis my research is arranged as follows. In line with the research process, I first make a general overview of transformations in biology research in preparation of analyzing scientific collaboration in detail. I employ the 'big science' concept to characterise transformations in contemporary life sciences research as big biology. By employing this concept, scientific and organizational developments in biology become part of a broader discourse on the expansion of science in modern society and the trend towards scientific collaboration. After placing developments in biology in a historic and cultural context, I characterize big biology as a specific networked form of big science. I show how scientific and technological developments in biology have interacted with social and political processes, resulting in increasing scientific collaboration. In contrast to more classic forms of big science like big physics, big biology has a networked character, which is underpinned by a socio-technical infrastructure with an important role for information and communication technologies. Moreover, I argue that big biology can be seen as a contemporary form of big science that corresponds with other trends in society and that indicates how big science in general has changed. In this context, I suggest that the analysis of big biology is exemplary of the broader trend towards scientific collaboration in contemporary science: the supersizing of science.

Supersizing focuses explicitly on the *process* of making science big. The increase of scientific collaboration in biology mirrors the building of scientific collaboration in contemporary society. My analysis of the three case studies not only shows how collaboration in biology has a networked structure, but it also illustrates how integration in biology takes place. By concentrating on the process of building big science I will explore how science is supersized and what kind of work is involved in the construction of scientific collaboration. I distinguish different styles of collaboration: projects have various rationales for collaborating as well as different orientations, resulting in diverse deliverables. I show how collaboration comprises different phases that require different types of work: the origin of collaboration, building connections and keeping it big. Within the process of building scientific collaboration, attention is paid in particular to what I call the 'projectification of science': the use of the project format to formalise scientific collaboration. I argue that as organizational structures, projects make it possible to connect scientific practice with government and industry, and that this directly affects scientific practice and the rhythm of science. In addition, I show how individual scientists play an important role in the shift towards the collectivization of science. In building scientific collaboration, scientists have to play new roles and in some respects become more similar to managers, politicians or businessmen.

Outline of the book

The book consists of three parts: a conceptual part, an empirical part and an evaluative part. The conceptual part, called "Big Biology" employs the term 'big science' to conceptualise transformations in biology. Starting with the debate on transformations in the organisation of research in the life sciences – asking whether biology is turning into big science or not – the first chapter *Big Science. Characterising transformations in science* explores the big science concept and compares it with other literature on scientific transformation and collaboration. The second chapter *Big Biology. Collaboration in the life sciences* compares developments in biology to traditional big physics. Some argue that biology is not big science, as technologies do not even come close to the size of instruments such as particle accelerators in high-energy physics, and consequently do not have the centralising force that constitutes big science complexes. However, I show how collaboration in biology differs from big physics on three fronts: it combines a different history of collaboration with the use of different kinds of technology and another social context. The chapter presents biology as a contemporary networked form of big science that emerged in interaction with the development of information and communication technologies.

"Life sciences live" – the empirical, second part of the book – takes the reader from the general conceptualisation of big biology to concrete examples of scientific collaboration. Subsequently, I present three different research projects that represent different styles of collaboration in biology. To explore these different forms of integration, I approach each case study from a different perspective, asking a different question. In the third chapter, *Seeing life in the oceans. New natural history*, I describe the Census of Marine Life as a contemporary example of natural history collaboration, taking a historical perspective to explore continuity and change. As the project can be compared to more traditional forms of scientific collaboration in natural history it enables me to study transformations in this style of collaboration. In contrast, the fourth chapter's Silicon Cell initiative is the result of contemporary developments in molecular biology, including the Human Genome Project, and shows how a new collaboration in biology is built. Next in *Growing a cell in silico. Constructing collaboration*, I analyse how the Silicon Cell project is deliberately staged as big science. By employing dramaturgical analysis – looking at collaboration as performance and the changing role of scientists – this chapter takes a sociological perspective on how collaboration is built. Finally, I investigate the building of a specific academic-industrial collaboration in the fifth chapter, *Developing a new vaccine. The innovation epidemic*. Since the VIRGO consortium is explicitly put forward as an 'innovative cluster' in which academia and industry work together, it becomes possible for me to investigate the actual formation of academic-industrial collaboration. Building on theories of innovation, I will explore how academia, government and industry become intertwined. As a result, the case studies represent three different processes that are fundamental to the construction of contemporary scientific collaboration in biology: the transformation of traditional collaboration, the building of new collaboration and the construction of academic-industrial collaboration.

The empirical part of this thesis provides the foundation for the final, evaluative part, entitled "Supersizing science". In this conclusion I pay attention to the structure and dynamics of scientific collaboration. Based on the empirical findings, the sixth chapter, *Unpacking collaboration in biology. Supersizing science*, analyses different forms of networks in biology. After looking into the structure, size and style of collaborations, the process of supersizing science is put centre-stage. I describe the work that has to be done to build large-scale scientific projects in biology and relate this to the growing importance of scientific collaboration in general. In addition, I propose to put the 'projectification of science' on the agenda of science studies. Finally, I turn the attention to networks of young scientists in my epilogue, *The future of science. The next generation*.

PART 1

Big Biology

CHAPTER 1

Big Science

Characterising transformations in science

"Life sciences is developing very rapidly into 'big science', with huge effort invested in it worldwide". This sentence can be read on the website of the Swammerdam Institute for Life Sciences of the University of Amsterdam.[6] Under the banner *Life Sciences, the science of this century* the institute presents itself as part of a global life sciences community that is nowadays changing fundamentally and becoming more prominent. A focus on the micro-level of molecules is providing new perspectives on life and increases the importance of the biosciences. Biology is very much alive, not only within the community that investigates life, but also in business, politics and media. According to geneticist Maynard Olson "The change is so fundamental, it is hard for even scientists to grasp" (Roberts, 2001: 1182). The term 'big science' is used to capture the enormous expansion of biology. More specifically, the Human Genome Project is considered the first big science project in biology (Kevles & Hood, 1992; Lenoir & Hays, 2000; Venter, 2007).

By employing the concept of big science in the context of biology, transformations in the organisation of research are framed in terms of growth and the movement towards collaboration. To illustrate, general features of big science are increasing numbers (money, manpower) as well as an increase in multi-disciplinary collaboration, the use of large, expensive instruments, the industrialisation of research, the tightening of relations between science, government and industry and internationalisation (Galison & Hevly, 1992; Sklair, 1973). In addition, by employing the term big biology, transformations in the life sciences are compared to similar developments in other scientific fields that are conceptualised as big science, most notably large-scale research projects in physics. The term big biology is especially employed by actors in the life

[6] Retrieved in 2004 from http://www.science.uva.nl/sils

sciences field. Big biology is used as a rhetorical weapon in the debate between scientists and policymakers in favour of the Human Genome Project and those opposing the project.

This *Big Biology* section employs big science as an analytical concept to study transformations in biology. I will show how the use of the big science concept helps to explore scientific and organizational developments in biology and places these transformations in a historical and cultural perspective. In order to characterize big biology, I will first examine the big science concept and its value as an analytical concept. Starting with the analysis of the debate on big biology, the first chapter will look into the origin and the history of the concept and distinguish different meanings of the term. These different meanings reflect the multi-faceted character of increasing dimensions in science and the various perspectives from which it can be studied. In this respect, the second chapter will analyse collaboration in biology as a form of big science.

Debating big biology

The Human Genome Project was accompanied by a heated debate about big biology. Some argue that the project can be seen as the start of big biology, while others firmly deny that biology is turning into big science (Check & Castellani, 2004; Davis, 1990; Rechsteiner, 1990; interview Remacle, 2006; Roberts, 2001: Venter, 2007).[7] In defence of big biology, the Genome Project is compared with the Manhattan Project that developed the atomic bomb during World War II, which is one of the biggest science projects in the history of physics (Lenoir & Hays, 2000). In contrast one of the headers in a discussion about the Genome Project clearly states: "The HGP Isn't 'Big Science'" (Hood, 1990: 13). Arguments in the discussion focus on the amount of money spent and the project management structure. Those defending big biology argue that the almost 3 billion dollar budget of the Human Genome Project is enough to make it a big science project, while for others biology does not qualify as big science because investments are small compared to physics or research into space. Furthermore, a central mode of organisation – as in big physics research – is seen as distinctive of big science endeavours, which turns the relatively fragmented, international structure of the HGP into an argument against the label 'big'. Since the 1990s both parties have stuck to their arguments and it is

[7] Personal communication with Prof. dr. André Goffeau, Institut des Sciences de la Vie, Université catholique de Louvain, Louvain-la-Neuve, Belgium: January 11, 2007.

safe to argue that the debate on transformations in the organisation of the biosciences has not reached any definitive conclusions yet.

However, careful analysis of the debate will reveal that the term big science is used as a symbol for a new, modern and more industrial way of organizing research. The big science concept is not primarily used to analyse the increasingly large dimensions in research, but it presents the Human Genome Project as a totally new way of doing biology. Next to new developments in technology, a specific mode of management has come into play, whereby scale, efficiency and work division are central. Moreover, authorship becomes collective. This new big science style of research sharply contrasts with more traditional images of science, symbolized by big science's antonym 'little science'. Small-scale science portrays research as an individual creative endeavour, resembling craftsmanship instead of an industrial way of working. This more romantic view of science also entails the image of the genius or distracted professor working alone in his study or laboratory (Doorman, 2004). In the case of biology, little science often has the character of investigator-initiated research in small laboratories (Roberts, 2001).

The debate on big biology, then, is about different ways to organise life sciences research, while the big science concept is mainly employed as a rhetorical weapon. Big biology has become a central phrase in the battle between scientists in favour of the Genome Project and those opposing it. At stake is not only the actual character of biology research but also the shaping of the future of science. Do we want the future of biology research to be little or big? Proponents of the Human Genome Project present big science as the new and more effective way to perform research: "scientific leaders agree that collaborative projects can produce results that would be impossible for specialized individuals working alone to achieve" (Check & Castellani, 2004: 546). In contrast, opponents of the Genome Project state that big biology undermines the very character of science, because it industrialises, bureaucratises and politicises research and dilutes creativity. To illustrate, genome sequencing is portrayed as 'massive, goal-driven and mind-numbingly dull' (Roberts, 2001). Molecular biologist Sydney Brenner even joked that sequencing is so boring it should be done by prisoners: "the more heinous the crime, the bigger the chromosome they would have to decipher" (Roberts, 2001: 1183).

As a result, it seems, the big science concept has provided discussants with a strong rhetorical sword for strengthening their case and draw a clear demarcation between traditional and new forms of organising life sciences research. But big science turned out to be a double-edged sword: it has both positive and negative connotations and could therefore be used by proponents as well as opponents of the Genome Project. Within the debate, big science is also put forward as an empirical concept, however. Whether or not the Human Genome Project should be considered big science became a major concern in the debate. Although this question could have given rise to a detailed analysis of transformations that take place in biology, the question was put forward in the context of the debate and was only answered strategically. Opponents of the Genome Project considered it big science while making use of negative normative connotations of the term and stressing discontinuity with normal research practice in biology. In contrast, the project's proponents emphasized the positive connotations of bigness or tried to win the argument from opponents by empirically denying the big science character of the Genome Project.

In sum, this analysis of the debate on big biology explicates the different ways in which the term big science is used. While life scientists and policymakers employ the different faces of big science, they do not reflect on the origin and the meaning of the concept and therefore do not explore the meaning of big biology in detail. For instance, it was not taken into account that bigness is of course relative (NRC Committee on Solar-Terrestrial Research, 1994), or that bigness can be found in various dimensions: geographic, economic, multidisciplinary and multinational (Galison, 1992). These different meanings that are inscribed into the big science concept only become evident when taking a closer look at the concept and its history. What does the concept cover? This is explored in the next section by investigating the big science concept as a starting point for discussing transformations in biology in a more nuanced way.

The meanings of big science

Opening the black-box of big science constitutes a starting point for exploring the way in which the concept may help us to grasp contemporary transformations in biology. By performing a conceptual analysis of big science, I will show how this concept is more then a rhetorical device in the fight between opponents and proponents of the Human Genome Project. Introducing the concept of big biology adds a specific view on transformations in science that can ultimately lead to a better understanding of contemporary developments in biology. To enfold the various meanings of big science, I will go back to the roots of the concept and discuss its development.

The origin of big science

The history of the term big science starts in 1961, when it was first introduced by Alvin Weinberg in his article on the *Impact of large-scale science on the United*

States (1961). Later, in his book *Reflections on big science* (1967) he defines the term as follows:

> Science has become big in two different senses. On the one hand, many of the activities of modern science – nuclear physics, or elementary particle physics, or space research- require extremely elaborate equipment and staffs of large teams of professionals; on the other hand, the scientific enterprise, both Little Science and Big Science, has grown explosively and has become very much more complicated. (Weinberg, 1967: 39)

Weinberg's attention to growth in science can be traced back to his participation in Americans large nuclear energy projects and his interest in science policy. In 1946 he became director of the Physics Division of Oak Ridge National Laboratory (ORNL) and in the period from 1955 till 1973 he headed the National Laboratory, the largest physics plant in the world and the largest factory of any type anywhere (Galison & Jones, 1999). However, Weinberg was more than a laboratory director: "In approximate chronological order, he was a physicist, a pioneer in nuclear energy, a reactor builder, a laboratory director, a lecturer, a writer, a thinker, a policymaker" (Zucker, 1995: 5). It is in this last role – as member of the President's Science Advisory Committee and director of energy R&D in the White House – that he came up with the term big science and composed his study.

In the preface of the book that comprises a collection of talks he gave during his years as laboratory director, Weinberg explains what inspired his reflections. First, he positions himself as director of a Big Science institute, a special feature of modern science in contrast to the traditional university. As director he feels obliged to justify the existence of the national laboratories and "the large sums of public money that pour into modern science" (Weinberg, 1967: v) and he also wants secure support as "the first job of a laboratory director is to assure continuing and ample support of the institution he directs" (idem). However, in the second half of the book Weinberg changes hats and becomes science advisor. Stating that the competitive and formal atmosphere in science committees in his opinion "can no more produce wisdom than design a camel" (Weinberg, 1967: vi), he gives his own view on the most troubling questions of modern science: the allocation of resources among competitive scientific fields and between science and other public enterprises, and "whether the new style of Big Science is blunting science as an instrument for uncovering new knowledge" (idem). With his book Weinberg aspires to provide a common language and framework for discussing issues related to the growth of science.

When addressing the origin of big science, however, most people will refer to the classic book of Derek de Solla Price: *Little Science, Big Science* (1963). This author elaborates on the concept of Weinberg, writing enthusiastically: "The large-scale character of modern science, new and shining and all powerfull, is so apparent that the happy term "Big Science" has been coined to describe it" (p. 2). Price started his career as a physicist, but as he explains it was a pile of journals that triggered his interest in the history of science and his engagement with big science (Price, 1983). Teaching at Raffles College – now the University of Singapore – he received a complete set of the *Philosophical Transactions of the Royal Society of London* from 1662 to the 1930s:

> I took the beautiful calf-bound volumes into protective custody and set them in ten-year piles on the bedside bookshelves. For a year then I read them cover to cover, thereby getting my initial education as a historian of science. As a side product, noting that the piles made a fine exponential curve against the wall, I counted all the other sets of journals I could find and discovered that exponential growth, at an amazingly fast rate, was apparently universal and remarkably longlived. (idem: 18)

While within the community of historians of science Price stood alone with his fascination for growth, his ideas were enthusiastically received by physicists during the Pegram Lectures he gave at Brookhaven. He rewrote those lectures into his book on big science which became an immediate success and connected very well with two new emerging fields in the 1960s: the sociology of science and information science.

Although Weinberg and Price belong to the same generation of physicists and share their fascination for big science, they engage with the big science concept in different ways. While Weinberg explicitly uses the concept to identify and evaluate transformations in modern science, Price's elaboration of the concept is more descriptive and focuses especially on the quantitative growth of science. However, in both accounts the emergence of big science is received with mixed feelings. On the one hand, the books can be read as celebrative descriptions of the growth of science as part of the development of science and society. On the other hand, the authors also critically reflect on the implications of big science. Particularly Weinberg perceives the growth of science as a problem, asking for example whether it is a good way to perform research or if investments in physics could not be better spend in other parts of society. In addition, Price contemplates the limits of growth. He observes the problems the growth of information poses and he takes the changes it requires, such as specialisation and teamwork, into account. He also suggests that scientists will lose their 'mavericity' (the ability to think outside the box and make unconventional associations) when working in large-scale research projects. This ambivalent stance towards big science, which is still very much visible in the two opposing views on big science in the debate on big biology, can be understood in the context of Modernity, in which the concept emerged.

Big science as a modern concept

The first books on big science are part of a long list of books with the term 'big' in the title that address growth as a distinctive phenomenon of modern society: *Big Business* (Fay, 1912, Hendrick, 1919, Drucker, 1947), *Big Government* (Pusey, 1945), *Big Democracy* (Appleby, 1945), *Big School* (Barker & Gump, 1964), *Big Cities* (Rogers, 1971), *Big Foundations* (Nielsen, 1972) and *Big Machine* (Jungk, 1986). These books all focus on overwhelming growth in modern society and its supposed inevitability. They focus on the implications of growth for the organisation of society and for individual man, often with a critical normative connotation. Growth is not only seen as an exponent of modern industrial society, but also as a source of its problems. Drucker (1947) even talks about the "Curse of Bigness" (p. 211). Within this tradition of 'big books' science is just the next sector of society that is described in terms of bigness, paying attention to scale and its positive and negative implications.

The term "big" is very much connected to the United States, the country of the Big Mac hamburger. So it is not surprising that it is also the place of birth of the big science concept and the home country of most of the other big books. When looking at the origins of the term Capshew and Rader observe: "It is no accident that the existence of Big Science was first discerned in the United States, where growth is a way of life and bigger is often viewed as better" (Capshew & Rader, 1992: 3). More specific, Galison (1992) places the roots of the development towards big science in the context of the Great Depression of the 1930s. In the United States it caused a counter reaction that admired bigness and gave rise to enormous building projects, such as Golden Gate Bridge, Hoover Dam and Empire State Building: "Without the cultural fascination of Americans in general for the large, the goal of building ever larger scientific facilities might have remained peripheral to other concerns" (p. 3). However, these writers on big science do not explicitly connect the origin of the concept to its cultural background of modernity.

The big books are written in the context of the broader cultural development of modernisation. In Modernity, growth is accompanied by the ordering and (re-)structuring of society (Berman, 1983; Kumar, 1995; Latour, 1993). Rationalisation and industrialisation processes give rise to so-called Taylorism and Fordism – efficiency and scaling-up – and are accompanied by bureaucratisation. Apart from the possibility of structuring and organising society efficiently, people strongly believed in progress. However, the modern condition also involves awareness of and reflection on the changes that take place. In these reflections modern life is fully embraced and at the same time harshly criticised: "To be modern is to find ourselves in an environment that promises us adventure, power, joy, growth, transformation of ourselves and the world-and, at the same time, that threatens to destroy everything we have, everything we know, everything we are" (Berman, 1983: 15). The modern order is even pictured as an iron cage (Weber, 1958). This critical stance towards the development of bigness is clearly visible in Weinberg's *Reflections on Big Science* (1967) and ultimately illustrated through the book *Small is beautiful* (1973) written by economist E.F. Schumacher. As this brief overview reveals, the context of modernisation is fundamental for the positive and negative normative connotations that are still connected to the big science concept today.[8]

Finally, the emergence of the term big science has to be placed in the context of science policy after World War II. Although the Manhattan project is frequently named as reference point for large-scale science, the big science term was coined *after* the war, in American society of the 1960s. In this post-war period important transformations took place in the relationship between science and society. During wartime, governmental investments in science increased enormously, but they also strengthened the political grip on the direction of scientific research. The ending of the war was therefore seized as an opportunity to renegotiate the relation between government and science (Galison, 1992; Guston, 2000; Jasanoff, 2005; Rip, 1998). The social contract for science based on the famous report of Vannevar Bush (1945/1980) can be read as a way to (re-)establish the divide between government and science after the War. He wanted to safeguard the continuity of government investment in science while also creating a protected space for science by putting it forward as an investment that always pays off, using successful scientific applications of the war as a symbol for the societal usefulness of basic science. Writings on big science reflect this view on science; fundamental science and the application of science go hand in hand and do not exclude each other. Moreover, the clear divide between policy, science and society coincides with the first generation of

[8] Currently, similar discussions surround the concept 'supersizing' that seems to be the new 'big'. The term 'supersize' also originated in America. It was first used in 1917 by a manager of the Firestone Tire and Rubber company, announcing the production of a new type of tire: the Firestone supersize cord tire (The Oxford English Dictionary Online. Retrieved June 11, 2008 from http://dictionary.oed.com). Recently the term became popular in the fastfood industry, which supersizes meals and the critical documentary about this process made by journalist Morgan Spurlock called 'Super size me' (2004) (Retrieved June 11, 2008 from http://www.supersizeme.com/). However, the term 'supersize' is also used in other contexts to indicate the process of becoming bigger, having a similar normative connotation as the term 'big'.

big science writers in which scientific practice – the actual research process – is not discussed.

The development of the big science concept

What happened with the 'happy term' after the 1960s? Common to early definitions of the concept is their focus on the description of increasing scales in science, measured in terms of money, scientists and publications. For instance sociologist of science Sklair defines big science short and simple "Big Science: Money and Manpower" (1973: 15). However, in later definitions different dimensions of growth are added. For instance, Lambright includes a timescale: "Big Science"-large-scale research and development (R&D) programs costing hundreds of millions, even billions, and lasting a decade or more" (1998: 260). In turn, Galison extends the dimensions of growth further again:

> [T]he big in Big Science connotes expansion on many axes: geographic (in the occupation of science cities or regions), economic (in the sponsorship of major research endeavors now costing in the order of billion dollars), multidisciplinary (in the necessary coordination of teams from previously distinct fields), multinational (in the coordination of groups with very different research styles and traditions). (1992: 2)

As a result, definitions of big science now indicate expansion in many directions: increasing numbers of scientists and publications, increase of investments in science, growth of scientific institutions, development of large instruments, increasing multi-disciplinary and multinational scientific collaboration, geographical expansion of science and increasing duration of scientific programmes.

Especially the period at the end of the 1980s and the beginning of the 1990s has been important in the development of the concept and its broadening meaning. Various publications on big science appeared and the highlight of this period is a conference at Stanford University in 1988, which resulted in the edited volume *Big Science; The Growth of Large-Scale Research* (Galison & Hevly, 1992). The preface of the book reports an interdisciplinary workshop with a diverse mix of scholars that employ the big science concept to look into a variety of subjects.

> Where past studies on big science typically counted dollars and personnel, and tabulated the funding sources that nourished large-scale research, we can now see more of the causes and consequences of the growth of science. (Hevly, 1992: 357)