Expansions of Nanotechnology

Harro VAN LENTE[a], Christopher COENEN[b], Torsten FLEISCHER[b], Kornelia KONRAD[c], Lotte KRABBENBORG[d], Colin MILBURN[e], François THOREAU[f], and Torben B. ZÜLSDORF[b]
[a] *University of Utrecht, Netherlands*
[b] *Karlsruhe Institute of Technology, Germany*
[c] *University of Twente, Netherlands*
[d] *University of Groningen, Netherlands*
[e] *University of California, Davis, USA*
[f] *University of Liège, Belgium*

Introduction

Little by little, nanotechnology has emerged amid enormous aspirations for new materials and fantastic promises of manipulating our world "atom by atom." While these grand visions continue to capture the imaginations of various audiences—and continue to be contested, as well—nanotechnology has developed into more than that. During the last two decades, many research programs and industrial R&D expenditures have resulted in actual products and tangible innovations. Nanotechnology, it seems, is expanding. But what does it mean to say that nanotechnology is expanding?

A standard view of technological expansion involves the "diffusion" of innovations. The famous 1962 study by Everett Rogers, *Diffusion of Innovations*, was rooted in the tradition of mass communication studies. It introduced how innovations spread according to logistic functions, that is to say, S-curves. It explained these patterns with an analysis of "early adopters," "majorities," and "laggards," tracing the ingredients that account for the decision of buyers whether or not to adopt the innovation. While Rogers's framework is a landmark in the study of technological change, it also has been frequently criticized, for instance, for taking the innovation as a static element, not changing during the S-curve, and for assuming a one-way trickling down of innovations to users. Generations of STS researchers have argued persistently against these assumptions (for example, see Geroski 2000, Metcalfe 1997). Yet, fifty years later, it appears that such terms are pervasive and have found their way into the vocabularies of journalists and policymakers. Another famous account of technological expansion was elaborated by Thomas Hughes in *Networks of Power*, a study that focused on Thomas Edison and his efforts to build an electricity grid. Here, the expansion of a technological system seemed to be determined largely by the interplay of the momentum and reverse salients of the system (Hughes 1983).

However, nanotechnology is neither a singular innovation, nor a specific system. The aforementioned accounts can therefore point to relevant aspects of processes of expansion, such as changes among the actors involved throughout the process, but other issues are likely to emerge, for instance, changes in the meaning and the substance of what is expanding. Nanotechnology promises to expand as an "enabling technology," that is, via other technologies and existing industrial R&D (Youtie et al.

2008). Moreover, in considering *what* is expanding, the epitheton of "nano" continues to create confusion. What counts as nanoscience or nanotechnology seems to differ according to various discussions of promises, anticipated markets, or concerns about risk. In particular, one can often observe a dual repertoire about the revolutionary character of nanoscience and nanotechnology: when underpinning promises or visions, "nano" is attached to a very extensive set of research and development activities; when linked to risks, the technologies at stake are not seen as very revolutionary (Rip 2006). Yet, while there is debate about what should count as nanotechnology, the unifying characteristic seems to be the persistence of great expectations (Selin 2007). Nanotechnology is a rhetorical entity in the first place, and it is now being filled in by actual research and development (Van Lente and Rip 1998, Milburn 2008).

So, nano expands—but in another way than the standard idea of diffusion. This volume testifies to various expansions of nanotechnology and other emerging technologies, some resonating with the more "classical" approaches to expansion mentioned before, but others not. For instance, there is *geographical* expansion. We have contributions from other continents than North America and Europe, testifying to the global expansion of nanoscience and nanotechnology. Also, the chapters show expansion from nanoscience to *innovation*. For a long time, nanotechnology was predominantly an issue of research (so, some argued that one should talk about nanoscience, instead of nanotechnology), but increasingly it has been turning into products. We also see expansions of the publics and audiences involved with nanotechnology, in addition to expansions of the cultural meanings attributed to nanotechnology. Likewise, we note the emergence of a wider set of questions, leading to and feeding into issues of policy and *governance*—articulated in terms much broader than regulation alone—as well as moves towards responsible innovation.

Throughout the contributions to this volume, we witness the deployment of various meanings of this notion of expansion. This volume testifies to the ambition of broad and general reflections on nanoscience and emerging technologies. The chapters deal with the manifold ways in which nanoscience and other emerging technologies expand. We have ordered the chapters into four parts: *expanding meanings*, *expanding publics*, *expanding innovations*, and *expanding responsibilities*. We would like to stress that this volume does not aim at a comprehensive and fully systematic overview of relevant questions related to the expansion of nanotechnology, but it provides a snapshot of the broad range of issues that emerge alongside the expansion of nanotechnology we are currently observing.

Expanding Meanings

The first section on *expanding meanings* explores how the word "nanotechnology" and its images disseminate in wider circles. It is no longer confined to a small community of engineers and policymakers. Rather, it spreads out in increasingly diverse communities, and it now concerns a broad array of actors. The volume starts with a study by *Arie Rip* and *Martin Ruivenkamp* about nanotechnology images, in particular, those that have become iconic and ubiquitous. This chapter poses the question: what images "do" as they circulate in the world of nanotechnology, and in society at large? A well-known example is the "nanolouse" image of a nanorobot treating blood cells. While images, in a basic sense, are visual representations, it is not clear what they represent in the case of nanotechnology. Images raise epistemological questions about what they represent; to be sure, a Nobel Prize-winning physicist once referred to such overwhelming images as a carnival of "nanobaubles" (Laughlin 2005: 134). Rip and Ruivenkamp's central interest is the notion of affordance, which they draw from design studies. Nano-images are consciously designed, including shapes and colors, and there has been criticism of the freedom nanoscientists allow themselves in their impressions. They also note that the images also enhance the general promise of nanotechnology. The image of the "nanolouse," for instance, is used to signify nanotechnology and to mobilize financial support.

The second chapter by *Susanna Priest* and *Ted Greenhalgh* studies the circulation of nanotechnology news and the way it is interpreted by the wider public. They study frames, schemas, and attitudes as predictors of reader reactions. They address four different applications (in electronics, food, medicine, and energy production, respectively) using four different "information order" frames (emphasizing social risk, physical risk, regulatory status, and benefits, respectively). Their results suggest that the current fixation on media framing as a determinant of reactions overlooks other important factors. Reader interpretations, or schemas, pre-existing attitudes toward science and technology in general, and toward authority in general, appear more important.

The chapter by *Frederick Klaessig* investigates the perennial difficulties to define nanotechnology. His example is the discussion on environmental, safety and health (EHS) aspects of nano-silver. He uses the concept of "undone science," introduced by Hess and colleagues. Klaessig also discusses an "old" and "new" material debate related to the U.S. EPA's recent conditional approval for HeiQ 20 AGS, a nano-silver product. The conclusion is that EHS issues were once peripheral to nanotechnology, but are now considered central to the responsible development of nanotechnology products. Likewise, other issues have been deemphasized, thus becoming "un-done." With the latter, data that were once valid information became invisible, but now return as terminology and research priorities shift. This chapter thus shows how meanings shift in definitions.

The fourth chapter by *Jan Youtie, Alan Porter, Kevin Boyack, Jose Lobo, Richard Klavans, Ismael Raforls* and *Philip Shapira* presents the results of a roundtable held at the S.NET 2011 conference about large-scale publication and patent databases. These databases represent an information source that allows for analysis of emerging technologies over time. During the roundtable, issues of definition were discussed, as well as the general lack of information about financial investments, and difficulties in working with unstructured text. The authors conclude that the major challenge is to link important databases. Large-scale databases can be very helpful in getting unobtrusive, scale-based perspectives on an emerging technology. At the same time, there is scope for improvement in conceptual clarity, missing information, messy and unstructured information, and linkages between datasets to enable researchers to better understand the development of emerging technologies.

Expanding Publics

Nanotechnology is not just stuff for scientists, engineers and policymakers. Due to increasing pressures to include stakeholders and society at large, the public for nanotechnology expands as well. In the U.K., for instance, the upstream engagement projects of Demos and others have led to several experiments to include the public. Workshops organized at the Center for Nanotechnology and Society in the USA (in

Arizona and California) and of NanoNed in the Netherlands are other examples. Several chapters in this volume account for the various routes in which this expansion is taking place.

In their chapter, *Stephanie Long* and *Rae Ostman* discuss the possibilities of theater to allow a broader public to reflect on nanotechnology. In general, theater has the power to make complex societal issues and scientific content relevant and compelling, engaging the public in topics that might otherwise seem intimidating or uninteresting. Their chapter discusses the work of the Nanoscale Informal Science Education Network (NISE Net) to develop, evaluate, and implement innovative dramatic and comedic programming to diverse public audiences. NISE Net theater performances and films have been held in museums and schools, aimed at sparking thoughtful conversations about the societal and ethical implications of nanotechnology.

The next chapter by *Elizabeth Kunz Kollmann, Larry Bell, Marta Beyer* and *Stephanie Iacovelli* discusses the topic of "Public Engagement with Science in Informal Learning Environments." They analyze the shift in informal science education (ISE) to go beyond the "public understanding of science" paradigm and to explore "public engagement with science." The authors argue that when making decisions about science and technology issues, it is important to involve not just expert voices but also public viewpoints. This chapter seeks to understand the spread of informal science education projects along this continuum and uncover groupings through the creation of a project catalog.

The chapter by *Craig Cormick* is concerned with the question of how to ensure that public participation in science and technology debates represents the breadth of public opinion. The challenge is how to gain the interest of people who are uninterested in science and technology. Through a series of discussions with recruited members of the Australian population who profess to being disinterested in science, Cormick sought to firstly discover more about their attitudes and values towards science and technology. He also tried to discover if there were different framings that would increase their interest in science and technology, and therefore increase the likelihood of them participating in engagement exercises and having their voices heard. Cormick concludes that uninterested citizens can become interested in science discussions, provided either that the discussions are not initially framed as being about science and technology, or that the discussions are reframed according to particular personal interests. The advice, therefore, is to use different communication, education and engagement strategies to reach different groups in public participation exercises.

Gregor Wolbring discusses the question of "Nanotechnology for Democracy versus Democratization of Nanotech." Given the rapid pace of development in nanotechnology products and processes, new challenges are introduced to various segments of society. It also influences how we relate to each other, locally and globally. Wolbring's argument is that our attitude to democracy is one aspect of how we relate to each other on the individual and societal level. Many countries define themselves as democracies. Various abilities are seen as essential for a functioning democracy, for democratic processes, and for active citizenship. It is often argued that the governance of science and technology should be democratized by including stakeholders and the public right at the beginning of innovation processes. Wolbring's focus, however, is on the question of how nanotechnology can and should support democracy, democratic processes, and active citizenship. His chapter performs an anticipatory analysis with regard to potential impacts on abilities seen as essential for democratic processes and active citizenship.

Expanding Innovations

An increasing number of products and processes now use ingredients or techniques that, in some way or another, are related to advances in nanoscience and nanotechnology. The expansion of nanoscience into the world of innovations has been accompanied both with both enthusiasm about new opportunities and new problems.

In their chapter *Guillermo Foladori, Edgar Záyago Lau, Remberto Sandóval, Richard Appelbaum* and *Rachel Parker* explore binational cooperation between Mexico and the U.S. regarding MEMS (microelectromechanical systems) and NEMS (nanoelectromechanical systems). While this cooperation is relatively recent—it started in the 2000s—its development illustrates at least two important issues. First, there is a strong confluence between military and civilian interests in this area. This common purpose has both facilitated and guided human resource training, as well as specialization within the institutions involved. Second, it shows that despite having little historical experience in such high-tech areas, Mexican institutions are nonetheless able to effectively develop new technologies, as long as the political will is present. However, the strong Mexico-U.S. ties that have been developed, with Mexico's efforts seemingly shaped either by the needs of foreign transnational corporations or the U.S. military, calls for further examination of how effectively this vital high-tech area will develop in terms of Mexico's own economic growth aspirations.

Clearly, the rise of nanoscience and emerging technologies raises new social research questions. In their chapter, *Christopher Lenhardt, Amy Wolfe, David Bjornstad* and *Barry Shumpert* consider how the Internet and social media may be used for new, innovative approaches to social science research. They present a review of existing literature about uses of the Internet to further social science research, concluding that many of the methodological issues that may be associated with Internet-based research are similar to more traditional social science research approaches. The authors discuss how a computer-mediated environment may enable rapid inquiry and assessment of complex, fast-changing research questions. The application of this approach is intended for a Department of Energy-sponsored (DOE) Ethical, Legal, and Social Issues (ELSI) activity at Oak Ridge National Laboratory (ORNL) that seeks to understand societal responses to emerging technologies, including nanotechnology, in the context of the research and development life-cycle.

In the next chapter, *Christopher Newfield* reflects on the ways in which—beyond specific policy incentives—German culture has contributed to the exceptional success of solar innovation in Germany. He also explores the seemingly paradoxical situation that, even while solar markets are expanding, the German solar industry is shrinking. He concludes that a different innovation model and policy approach may be necessary, in order to ensure the further development of technology that fully exploits solar energy's sustainable potential.

Expanding Responsibilities

New developments in nanotechnology have also given rise to a host of regulatory and governance issues. As new terrains are being explored and exploited, established regulatory frames have to be adapted or reinvented. In their chapter, *Elena Pariotti* and *Daniele Ruggiu* critically examine how nanotechnologies can be governed in Europe. They start from a rights-oriented perspective and consider the interplay of hard legal legislation, a wide range of soft law instruments, and different types of actors. They also consider the presence of ethical committees and ethical advice, which raises questions about the correct relationships between legal and ethical normativity within the governance of emerging technologies. An "ethicisation of technologies" is looming, they argue, that is, the tendency to exceed in framing the governance of technologies in ethical terms, and the risk of the substitution of law with ethics. Soft law, they argue, should not be confused with ethics.

In the next chapter, *Sally Randles* and her co-authors present the results of a roundtable held at the 2011 S.NET conference with academics and policymakers from Europe and the U.S. This transatlantic conversation was designed to stimulate considerations of recent regulatory decisions related to responsible innovation and governance. While the statements and subsequent discussion clearly showed a variety of perspectives, partly related to the diversity of disciplinary backgrounds, a number of commonalities and common concerns across regions emerged. A first common theme was the need for responsible innovation, not just to avoid doing harm, but even more to strive for "doing good" and achieving benefits. Furthermore, and resonating with other subthemes of our volume, the need was highlighted to give more attention to commercialization, and also to move beyond science and involve the public as a focus of responsible innovation practices. Finally, it was urged to look beyond the western countries, and particularly to Asia, with its cluster of countries with substantial nanotechnology research and commercialization activities. That is to say, further expansion.

In their chapter on "Crossover Research," *Rune Nydal, Sophia Efstathiou* and *Astrid Lægreid* discuss the issue of integrated knowledge. They define "integrative" research broadly as research that tries to mesh humanities and social science knowledge or methods, with the practice of a natural or life science project. Their chapter focuses on integrative research that has a professed ethical or societal, normative aim: what has been pursued under the label of "technology assessment" or "ethical, legal and social aspects" (ELSA) programs. In particular, they study recent ELSA calls from the Research Council of Norway. For humanists and scientists positioned in such an integrated project, the value of integration in general becomes a pressing issue of daily work. The authors find that the reasons why integration is seen as valuable varies considerably—sometimes the reasons may not even be clearly articulated. People involved in integrative research may hold different and even conflicting interests, as well as different ideas about what integration involves in the first place.

The volume ends with the chapter by *Noela Invernizzi*, based on her keynote lecture from the Arizona 2011 conference. She analyses the position of unions from diverse regions of the world about the risks and implications of nanotechnology for workers. By interviewing union leaders and analyzing fifteen different union declarations that were produced between 2004 and 2010, Invernizzi reconstructs the origins of the nanotechnology debate within the union movement, attending to the various positions, concerns and demands. She concludes that the potential implications of nanotechnology for employment have received limited discussion within unions so far, in some cases because it is still not perceived as important (Australia and the United States), and elsewhere because unions are overwhelmed with existing problems, and nanotechnology seems to be a long-term concern (Latin America). Only in Europe has the topic begun to be discussed, ranging from optimism over the possible creation of jobs to fears about an industrial restructuring in a context of crisis.

In conclusion, this volume explores the various expansions that mark the development of nanotechnology and other emerging technologies: shifting meanings, new audiences, innovative trajectories, and the rearrangements of responsibilities.

New questions, new concerns. Little by little, it will be sorted out.

Acknowledgments

We would like to thank the organizers of the 2011 S.NET conference held in Tempe, Arizona, who provided a wonderful platform for the authors and the editors of this book to meet and discuss their research. This book would not have been possible without the financial support of the sponsors of the 2012 S.NET conference—to take place at the University of Twente in Enschede, The Netherlands—and in particular, the Institute of Innovation and Governance Studies (IGS) of the University of Twente. Finally, we would like to thank wholeheartedly Evelien Rietberg, who spent her weekend hours helping prepare the manuscript.

References

Geroski, P.A. (2000) Models of Technology Diffusion, *Research Policy*, **29**, pp. 603-625.

Hughes, T.P. (1983) *Networks of Power: Electrification in Western Society, 1880-1930*, Baltimore: John Hopkins University Press.

Laughlin, R. (2005) *A Different Universe: Reinventing Physics from the Bottom Down,* Basic Books, New York.

Youtie, J., Iacopetta, M., and Graham, S. (2008). Assessing the Nature of Nanotechnology: Can We Uncover an Emerging General Purpose Technology? *Journal of Technology Transfer*, **33**(3), pp. 315-329.

Metcalfe, J.S. (1997) On Diffusion and the Process of Technological Change, in: Antonelli, G., and DeLiso, N. (eds.) *Economics of Structural and Technological Change*, London: Routledge, pp. 123-144.

Milburn, C. (2008) *Nanovision: Engineering the Future*, Durham: Duke University Press.

Selin, C. (2007), Expectations and the Emergence of Nanotechnology, *Science, Technology, and Human Values*, **32**(2), pp. 196-220

Rip, A. (2006) Folk Theories of Nanotechnologists, *Science as Culture*, **15**(4), 349–365.

Rogers, E.M. (1962) *Diffusion of Innovations*, Glencoe: Free Press.

Van Lente, H., and A. Rip (1998) The Rise of Membrane Technology: From Rhetorics to Social Reality, *Social Studies of Science,* **28**(2), pp. 221-254.