Techné: Research in Philosophy and Technology

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Editorial: Nanotech Challenges, Part II

Joachim Schummer, Editor of *Hyle*
Davis Baird, Editor of Techné

Since the publication of Part I of our joint special issue on Nanotech Challenges (see Techné 8.2 & Hyle 10.2), several international conferences have taken place that brought together scholars from the humanities and the social, natural, and engineering sciences to reflect on the challenges posed by nanotechnology. These included *Nanotechnology in Science, Economy and Society*, University of Marburg, 13-15 January 2005; *Nano-Ethics*, University of South Carolina, 2-6 March 2005; *Nano Before There Was Nano*, Chemical Heritage Foundation, Philadelphia, PA, 18-19 March 2005. In addition, numerous research groups worldwide, who used to investigate the science-technology-society interfaces, have put nanotechnology at the top of their agenda; international expert groups are being formed; and national centers will soon be established in the US and UK.

Of course we hope that our joint special issue is not only timely but also influential on the debate and the shaping of a growing international community. Since the nano-hype seems to have infected the humanities and social sciences, it is important to keep scholarly standards high and to provide space for critical and independent views that might not always be welcome in commissioned reports.

While the corresponding Part II in Hyle 11.1, focuses on ethical issues of nanotechnology, the present Techné collection consists of papers that combine theoretical with practical reasoning. The first two contributions each point out that epistemological issues of nanotechnology are related to ethical issues. The third paper transfers concepts of the public negotiation of truth to the public negotiation of what is worth funding in nanotechnology. The forth suggests a philosophical research agenda that integrates theoretical and practical issues of nanotechnology.

With reference to Kant's distinction between phenomena and noumena, Alfred Nordmann argues that some areas of nanotechnology are *noumenal* technologies in the sense that their products resist our capacities of experience, imagination, and causal representation. Contrary to the ambition of mastering nature, products of *noumenal* technologies appear similar to brute nature by provoking a mixture of awe and abhorrence. He concludes that, because the gap between our manufacturing and representational capacities raises ethical concerns, all the educational efforts to make the nanoscale imaginable bear an ethical dimension.

In his epistemological analysis of scanning electron microscopy (SEM), Joseph Pitt argues that SEM plots, although they convey exact information, should not be called images because they are not exact representations of reality. The talk of images invokes the metaphor of plain seeing, which is misleading in many ways. Not only does it suggests naive epistemological realism and an incorrect view of our knowledge of the nanoscale, it also misinforms ethical considerations that are based on the view of our knowledge.

In his case study on a Danish research group that moved from surface science to nanotechnology, Arne Hessenbruch analyses the interfaces between science and the public. Unlike former science studies that have focused on epistemological issues, his focus is on emotions, like pleasure and exhilaration, which are conveyed by newspaper articles, high gloss magazines, movies, and even research papers for the intrascientific public. He argues these emotions play an important role in the struggle for funding and are a driving factor for the current nano hype.

Drawing on the work of the Dutch philosopher Herman Dooyeweerd, Marc de Vries develops a comprehensive philosophical research agenda for nanotechnology. Rather than taking nanotechnology as a complex whole, he distinguishes between fifteen aspects, including physical, biotic, psychological, social, economic, ethical, and religious aspects. For each of these aspects he discusses particular issues and how they could be related to each other on a more general level.

Finally, we hope that our experiment of jointly editing a special issue will become a model in the future whenever a topic concerns readers of more than one journal. Again, readers of Techné are encouraged to read the corresponding Part II of Nanotech Challenges in Hyle 11.1, and vice versa.

Noumenal Technology: Reflections on the Incredible Tininess of Nano[1]

Alfred Nordmann
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Noumena are distinct from *phenomena*. While the latter are the things as they appear to us and as we experience them, the *noumena* are the philosophically infamous and mysterious things-in-themselves.[2] The "*noumenal* technology" referred to in the title of this paper would therefore appear to be a contradiction in terms: Technology is a human creation that involves human knowledge and serves human needs; this firmly roots it in phenomena and it appears absurd to speak of technology that exists beyond human perception and experience among the things-in-themselves. The *noumenal* world is nature uncomprehended, unexperienced, and uncontrolled; it is nature in the sense of uncultivated, uncanny otherness. By speaking of "*noumenal* technology" this paper argues that some technologies are retreating from human access, perception, and control, and thus assume the character of this uncanny otherness.

Three seemingly disparate reflections prepare the formulation of this thesis, and the remaining sections work to establish at least its plausibility.

The Emperor's New Guitar

Under the heading "US-researchers play nano-guitar" the following brief notice appeared not long ago in a German newspaper:

> US-researchers struck the smallest guitar string in the world: The journal *Nature* reports that a nanocarbontube only a few millionth of a millimeter wide vibrates with an inaudibly high frequency. (*Frankfurter Rundschau* September 16, 2004)

Too small to be seen, too high-pitched to be heard, this is clearly not much of a guitar. Indeed, one might wonder why anyone would call it a guitar in the first place. In fact, the *Nature* editorial does not refer to a guitar at all but likens the observed effects to "the strings of a violin" (Cleland 2004).[3] Since this does little to clarify matters, the article explains that the resonance frequency of the nanotubes can be tuned—and both, the notions of resonance and of tuning suggest the functional similarity to a stringed musical instrument. The analogy can now be extended to say that the functionality may lead to devices or instruments. Researchers may well begin to play on these instruments, though not to produce music but, for example, to amplify the instrument's informational state and thus to make it an "electronic detector—one that can 'hear' its own motions." The editorial concludes by expressing the hope that "[f]uture efforts may add multi-stringed instruments to the present device—and perhaps, in time, arrive at a full symphony orchestra" (Cleland 2004).

The nano-guitar adds further evidence to Joachim Schummer's thesis about the aesthetic origin of molecular nanotechnology. He argues that the technical functionality of molecules was suggested by a certain way of looking at molecules within supramolecular chemistry, where molecular structures became associated with artifacts like baskets, rotors, or chains (Schummer forthcoming). Assuming the position of the newspaper reader, however, we might go on and probe a little more deeply what it means to imagine as a familiar instrument like a violin or electric guitar something that is utterly remote to our senses, namely a carbon nanotube which is suspended between two gold electrodes and tuned by the variation of gate voltages.

Mastery of Nature

Francis Bacon's famous dictum that "knowledge is power" ties the advance of theoretical understanding to the expansion of experimental control.[4] We know that we know when we can bring things about on the basis of our knowledge. It is worth asking whether the inverse holds and whether the advance of technical control is tied to representations of what we do. Do we have mastery of nature only to the extent that this mastery is rehearsed and reproduced in thought?

In recent years, the philosophy of instrument and experiment has pressed this issue by showing that experiments and technical constructions can have a life of their own, that is, independent of scientific theory (for example, Baird 2004). Accordingly, the general claim that technical control is accompanied by conceptual representations must be distinguished from the more specific, untenable claim that technical control consists in the application of theoretical knowledge. Once this distinction is kept in mind, the relation between power and knowledge can be formulated in a more innocuous and intuitive manner: Technology involves humanly initiated causal processes. Some have very detailed knowledge of how such processes unfold. Others imagine only the turn of a switch and a resulting action. Yet others have a largely intuitive and physical mastery of, say, their bicycle and equate the causality of stopping, turning, or adapting gear with the causal powers of their own, technically extended bodies. In all these cases, technical mastery is attended by representations of how this power is exercised.[5] Indeed, it appears inconceivable to say that we technically control nature without possessing at the same time some conceptual image—no matter how impoverished—of the causality that is implied by the very notion of control. This raises the question whether the nano-guitar or other technologies are such that we fail to form such a conceptual image even though we must do so in order to assert responsibility and control.

It is important to distinguish the case where we must, but fail to imagine the workings of a technology, from the familiar case where we need not do so and where, in fact, we do so only in a most rudimentary way. This familiar case goes under the name of "black-boxing" and was described as early as 1919 by Max Weber in "Science as a Vocation":

> Excepting physicists who know the subject, those of us who take a streetcar have no idea how it sets itself in motion. We do not need to know this. It is enough to "count" on the behavior of the streetcar, we orient our actions accordingly; but we know nothing of how one constructs a streetcar so that it moves. Savages know their tools incomparably better...Increasing intellectualization and rationalization therefore do *not* imply increasing general knowledge of one's conditions of life. It implies something else, namely knowledge of or faith in the fact that, if *only one wanted to*, one *could* find out any time, thus that in principle there are no secret, incalculable forces entering in, that instead—in principle—the things can be *mastered through calculation* (Weber 1988, 593ff.).

Weber's case of the streetcar refers to a most impoverished but still existing connection between technical control and causal representation. In cases like these we represent our technical interventions in the world only as a generic causal relation between input and output: When I flip this switch, some action will commence or conclude even if I know nothing about the mechanism through which this is effected.

However, the nano-guitar or genetically modified foods, ambient intelligence, nanoparticulate sensors, and pervasive large technical systems raise the question whether technical control is decoupled far more fundamentally even from generic representations. In these cases, it might not help to look up in a book how the technology operates because all the explanations and illustrations in the world do not yield perspicuity. Indeed, these technologies may well become more unfathomable when we are asked to imagine their unimaginably intricate workings that lie beyond the reach of our senses. Also, for these technologies the notions of use or of a user and thus of control are meaningless to the innumerable non-users who find themselves conscripted into their technological networks. Technological interventions, like the nano-guitar, might be operating in the background, unknown and unknowable to us. They therefore do not become objects of experience—and what is no object of experience remains unrepresented and does not prompt the formation of a conceptual image of its working. To the extent that they remain in the unconsidered and unconceptualized background of our actions and lives, these technologies are much like brute and uncomprehended nature—instead of knowing them, we merely know of them. Their looming presence and potential efficacy does not appear as an extension of our freedom or our will, but as a mere constraint, even perhaps as a threat. Where technical and intellectual control come apart, the humanly induced workings of technology no longer signify mastery of nature but take on the character of nature itself.

This would further suggest that the novelty of these technologies is not the *Technisierung der Natur* (nature taking on the character of technology) which may be as old as agriculture but, instead, the *Naturalisierung der Technik* (technology taken on the character of nature).[6]

(Mis)Understanding Kant

In all our attempts to understand the philosophy of Immanuel Kant, we inevitably encounter the question regarding the "thing-in-itself." This question can be answered in a roughly correct and in a woefully incorrect manner. By speaking of "*noumenal* technologies," this paper will be flirting with the incorrect one.

According to the roughly correct account, the things-in-themselves are nature unrepresented in experience—if it were possible to speak of this nature at all.[7] We do not and cannot know the things-in-themselves or nature "as it is" (with the one tenuous exception, perhaps, of our own nature as free, intellectual beings). This unknowability of the *noumena* or things-in-themselves can be described as a limit to theoretical understanding. Put positively, it represents the characteristic effort of modernity to push back the alien and uncanny otherness of nature. How things appear to us as *phenomena* in experience is already structured by the mind, already subject to mathematization and intellectual control. As opposed to brute nature, the phenomena are already civilized.

Now, the woefully inadequate account goes something like this: If you want to know what *noumena* or things-in-themselves are, consider things like atoms or molecules. After all, we cannot directly experience them and yet our *phenomenal* world of experience is composed of them. This interpretation is obviously incorrect because we formulate and test scientific theories about atoms and molecules. These are therefore objects of knowledge and it was precisely for all objects of knowledge that Kant showed how we constitute them as *phenomena* in time and space, as subject to causality, etc. As far as science is concerned, atoms and molecules are definitely no things-in-themselves that are unstructured by our minds. As objects of knowledge they come with, they are part and parcel of our theoretical representations.[8] But perhaps, as far as technology is concerned and when the bond between understanding and technical control is severed, atoms and molecules might as well be things-in-themselves. *For all practical purposes*, that is what they are. In what follows, the nano-guitar and other examples will be recruited to suggest that nanotechnologies, in particular, are thought to act in ways that remain, quite literally, inaccessible and in a size-regime that despite all our scientific theories remains unknowable.[9]

Noumenal Technology

Taken together, the preceding remarks suggest the thesis or at least explain the title of this paper: *Noumenal* technologies arise where the link between representation and control is broken, that is, when we successfully create artifacts and perhaps a technical agency whose presence and action are inscrutable to us and, in effect, indistinguishable from the presence and action of the natural processes that serve as an unconsidered background and framework of our lives.

In order to substantiate this thesis, it needs to be shown that with the nano-guitar and numerous associated technologies, technical intervention eludes imaginative or conceptual grasp. Indeed, Günther Anders has shown something very much like this half a century ago for nuclear technology.[10]

> As engineers, at least as engineers of nuclear weapons, we have become omnipotent—an expression that is little more than a metaphor. But as intellectual beings we do not measure up to this omnipotence of ours. In other words: by way of our technology we have gotten ourselves into a situation in which we can no longer conceive (*vorstellen*) what we can produce (*herstellen*) and do (*anstellen*). What does this discrepancy between conception (*Vorstellung*) and production (*Herstellung*) signify? It signifies that in a new and terrible sense we "know no longer what we do"; that we have reached the limit of responsibility. For to "assume responsibility" is nothing other than to admit to one's deeds, the effects of which one had conceived (*vorgestellt*) in advance and had really been able to imagine (*vorstellen*) (Anders 1972, 73f; see also 33-40, 88f, 96-99).[11]

Anders reflects the incommensurability or absolute disproportionality between the scale of human action and the scale at which its effects unfold. In one size regime occurs a perfectly conceivable technical malfunction or a human reaction to a perceived threat, in quite another size regime there is the perfectly predictable, yet utterly inconceivable end of humankind. The nano-guitar, genetically modified foods, or pervasive technical system present a different kind of inconceivability, one that still needs to be characterized.

Rather than serve as an instrument for deliberate action in the world, such *noumenal* technology recedes into the uncanny otherness of nature and resists our attempts to make it an object of experience and knowledge. Its elusive character can be characterized, perhaps, in reference to Gerhard Gamm's conception of technology as a medium that structures human action without being present in experience as a structuring device—somewhat like blood in our bodies or money in our economies (Gamm 2000).[12] As such, this technology is knowledge-based and yet no tool or instrumental application of scientific knowledge. By the same token, this technology does not prefigure the scientific manner of recruiting calculable effects of nature (compare Heidegger [1977]). Instead, the mutual dependence of science and technology, of knowing and acting comes asunder in *noumenal* technology and Max Weber's story of progressive rationalization unravels.

By definition, science involves objects of knowledge and experience. To the extent that we see the world through the glasses of science, we remain—as Kant would say—the lawgivers of nature and consider *phenomena* in their causal or structural contexts. This is certainly true also of nanoscience and its understanding of nanoscale phenomena. In contrast, *noumenal* artifacts like the nano-guitar turn out to be in essential respects not even objects of science, even though they were discovered, controlled, and explained by scientists and engineers. Where technical artifacts are no objects of experience, the scientific and technical rationalization of the world and the disenchantment of nature give way to a celebration of magic and enchantment. Naturalized technology is a mere medium for action, so deeply embedded that it eludes reflection or deliberate use, let alone rejection. As technical control outstrips intellectual control, our progressively expanded technical reach might thus prove regressive as regards the mastery not only of nature but of our own destiny.[13]

Genetically modified foods serve as a paradigm for this and, depending on how it develops, so may nanotechnology. They begin as purposeful interventions in nature (e.g., pesticide resistance) but their effects cannot ordinarily be observed or tracked even as they propagate through human bodies. Rather than reduce anxiety by assimilating nature to culture and by rationalizing the world through technology, such *noumenal* technology heightens anxiety. It does so by implicating us in a pervasive technical environment that is just as uncanny as is nature with its imperceptible germs, viruses, or bacteria on the one hand, its disruptive and haphazard earth-quakes, lightning-strikes, or volcanic eruptions on the other. These technologies enter the sphere of rationality only when we assume the mostly fictitious vantage-point of a user whose judgement is not based on immediate physical experience but on statistically mediated experiences of benefits relative to costs or risks. The farmers, for example, who choose to plant genetically modified crops may experience an increase in yield and they can thus articulate a rational justification of their choice. But even these farmers, of course, have no experience of the genetic modification when they are cooking and ingesting their crops, and even they may find the presence of this unexperienced modification uncanny.

This regressive rather than progressive aspect of *noumenal* technology in regard to the mastery of nature is of a different character entirely than the familiar problem of not being able to imagine all the consequences of some technical intervention. Indeed, even where we have technical control with attendant representations, inadvertent effects may well get ahead of our imaginative abilities—as happens in the case of the "sorcerer's apprentice" and whenever the effects of our actions get "out of hand." Here the limits of imagination consist in a computational inability to think through easily representable but highly complex pathways and interactions. In contrast, *noumenal* technologies and *phenomenal* (scientific) representations are incommensurable from the beginning since essential features of the technology cannot enter into phenomenal representations at all. Again, Günther Anders was perhaps the first to carefully distinguish the practical inconceivability of the infinitely long chain of effects that follows upon any human action, from the absolute inconceivability of the infinite magnitude of the single, perfectly predictable, and immediate effect of a nuclear attack (see Anders 1972, p. 34). The *noumenal* technologies discussed here involve a similar incommensurability. It results from the fact that the indefinitely near- or medium-term agency of certain technologies is shielded from our sensory modalities. To the seismic movements of nature that may eventually produce an earth-quake, human engineering is adding further causal processes that operate behind our backs with possibly catastrophic consequences.

The Absolute Smallness of Nano

The elaboration so far of the thesis has shown that its plausibility hinges on the claim that the nano-guitar is not an object of science, even though it was presented, discussed, and even though its construction and workings were explained by scientists in the journal *Nature*. This apparently paradoxical claim needs to be elucidated and, ideally, justified. Here is the argument in a nut-shell: As a nanotechnological artifact the nano-guitar is essentially small. Its "incredible tininess" and ability to perform defined functions at the nanometer scale is its very point and apparently the point of much (though by no means all) nanotechnology.[14] If something is so small that we cannot imagine its size and if yet we feel that we must imagine its size in order to grasp its essential feature as a nanotechnological artifact, we will be attempting and failing to grasp something *noumenal*, namely how small or large something really is. In contrast, like everything *noumenal*, absolute size is never a feature of objects of science or knowledge. These objects are constituted and represented as they phenomenally appear to us and our measuring apparatus, that is, as relatively large or small, as measuring so much on some scale, as comparatively smaller or larger than something else. In other words, we can know and imagine a great deal about the nano-guitar, but we cannot know at least one of its essential features as a nanotechnological artifact. The nano-guitar therefore demonstrates simultaneously the expansion of technical control and the limits of human understanding, and because of this it is an object of technology that is not at the same time an object of science.

What is represented in the journal *Nature* is the nano-guitar as a *phenomenon*, namely as it appears to scientists by way of their representational tools and within their traditions and conventions of representing states of matter and motion. The readers are told how the guitar is constructed and how it works, they can learn to understand the relation of the parts to the whole, and they can refer its interesting properties to a rather general theoretical account of atoms and molecules. In other words, the readers of *Nature* will know quite a bit about the nano-guitar and in respect to this knowledge, the nano-guitar is clearly an object of scientific, though not ordinary experience. There is one feature of the nano-guitar, however, which is not represented to the scientists and which alone makes it a specifically nanotechnological device, and that is its size. We see in images and print a perfectly macroscopic representation that appeals to our sensory modalities. For the most part this image of the world at the nanoscale is to be taken quite literally: in this world, if you produce an electrical impulse here, you will observe some oscillation there. But like all scientific articles, this one does not (and need not) tell us how small this world really is. We are simply informed, for example, that 1 centimeter in the image before our eyes corresponds to 1 nanometer. Here, there is no literalness but a translation of sorts—the nanoworld has been scaled up for the purposes of human perception and understanding. As long as the scientists realize that nanometers are greater than angstroms and smaller than micrometers, that they are considering molecular rather than atomic or astronomic scale, all is well. Scientists are not required to correct for this scaling effect or to somehow subtract in their minds the magnification that was provided by their instruments.

Accordingly, it is not just a lay audience that has to deal with the incredible tininess of nano but also nanoscientists who learn to manipulate individual atoms, including the creator of nanoscience's most conspicuous accomplishment regarding the positioning of atoms at will. Don Eigler used 35 xenon atoms to spell the letters "IBM" with all three letters spanning less than 3 nanometers, and yet he declares fifteen years later: "If you can imagine anything that's a billionth of anything else, you are way of ahead of me" (Eigler 2004).[15] Put another way, as far as Don Eigler is concerned, the grouping of xenon atoms measures precisely 2 to 3 nanometers across and at the same time is unimaginably small. The first half of this statement refers to relative size as measured at the nanometer scale, the second half of this statement refers to absolute size and how small something really is.

Eigler's nanotechnological achievement draws attention to an incommensurability that goes entirely unnoticed in science and that does not require our attention in regard to most technology. While a scientifically trained intelligence can imagine the world at the nanoscale, it cannot and need not imagine the length of a nanometer. For science, it is not important and perhaps even an absurd undertaking to imagine the length of a nanometer. In this respect, the "problem" of imagining the length of a nanometer is no different from trying to imagine the length of a meter.

Indeed, it would be quite absurd to assume that to the question "how long is a meter?" there should be an answer in terms of absolute size. Clearly, the meter is a perfectly arbitrary unit and, as such, the best answer provides a mere definition in terms of some non-deformable physical units. It has been an interest of science to provide the terms for such a definition. Also, it is of interest to science that there is a reliable standard of measurement. Beyond that, to ask about the length of a meter is not a scientific question. Not long ago, the questioner would have been referred simply to the "standard meter" in Paris—the length of a meter was defined by the length of that object which served as the international standard. One way or another, the scientific definition involves only relative size, either relative to certain physical operations or to the standard object in Paris. And if one wanted to how long a meter was in terms of human experience, the approximate answer would refer to the human being and the gesture that a meter is about so-and-so long relative to our body in space.

The nanometer is not so defined. There is no "standard nanometer" on display in some vault that provides visual comparison, and there is no gesture indicating that it is roughly so-and-so small. Since the nanometer is a billionth of a meter, this is no problem for science. The size of nanoscale objects is perfectly secure relative to other size scales. But the scientific definition does not satisfy the demand for another, more intuitive grasp of how long a nanometer is. Since even scientists cannot imagine the billionth of anything else, we apparently need to find a way of imagining the nanometer in a way that is not relative to the meter and that substitutes for the absence of any physical relation to human gestures or sensory modalities. Since the length of the nanometer and the relation of a billionth to a whole are beyond the realm of appearances, this amounts to a demand for an intuitive grasp or absolute knowledge of how long a nanometer really is. This demand is given expression in countless introductory presentations and publications of nanotechnology. Those that are addressed to scientific peers and those that reach out to a general audience usually begin with more or less impressive, more or less desperate attempts to illustrate how long a nanometer is.

Any request to know what is *noumenal* or is a property of the things as they are themselves must, by necessity, fail. This holds true also for the request to illustrate and imagine how long a nanometer really is. According to Kant, objects of experience are constituted not only in time and space or the framework of causality but also in terms of magnitude and quantity. As Kant shows especially for infinitesimals, this means that we do not apprehend size as such and how large or small things are in and of themselves (compare Kant 1997, A166ff.). Instead, infinitesimals are represented in a continuum of intensities and effects and thus only in so far as they contribute to human experience. It would be nonsensical to imagine infinitesimals as such or independent of the calculus. Extending Kant's argument, Ludwig Wittgenstein tells us that it would be a similar mistake to take "meter" or "nanometer" for anything but grammatical.[16] We use these terms to relate things to one another but they have no natures or properties of their own. It would be nonsensical, therefore, to ask how small or large a nanometer is, especially in the absence of any physical rituals or gestures that can serve as symbolic substitutes. What we have, instead, are only the rituals of taking us to the limits of our imagination: "To see a nanometer would be like seeing a postage-stamp from half way across the earth"—which says no more or less than that we cannot do it, that we can neither see nor imagine it. And yet we attempt again and again to imagine the unimaginable, running up against the limits of comprehension. Take this famous anthologized reflection on the large and the small from Kenneth Ford's 1958 introduction to *The World of Elementary Particles*:

> On the submicroscopic frontier of science (as well as on the cosmological frontier) man has proceeded so far away from the familiar scale of the world encompassed by his senses, that he must make a real effort of the imagination to relate these new frontiers to the ordinary world…One of the best ways to try to visualize the very great or the very small is by analogy. For example, to picture the nucleus, whose size is about 10^{-4} to 10^{-5} of the size of an atom, one may imagine the atom expanded to, say, 10,000 feet (10^4 feet) or nearly two miles. This is about the length of a runway at a large air terminal such as New York International Airport. A fraction 10^{-4} of this is one foot, or about the diameter of a basketball. A fraction 10^{-5} is ten times smaller, or about the diameter of a golf ball. A golf ball in the middle of New York International Airport is about as lonely as the proton at the center of a hydrogen atom. The basketball would correspond to a heavy nucleus such as uranium (Ford 1991, 18 & 21f.).[17]

Ford sets out to relate the ordinary to the extreme. This gesture is repeated again and again in the context, for example, of nanotechnology. The relation of 1 nanometer to 1 millimeter, we are told, is like the relation of the distance between New York and Boston to the distance between earth and sun.[18] These analogies present relative magnitudes and succeed at communicating the loneliness of the golf ball in the middle of today's John F. Kennedy Airport in New York. They help us imagine the world at the atomic or molecular scales, a bit like helping people imagine a foreign country or exotic culture. At the same time these analogies strain and fail to acquaint us with the size of these worlds, their distance from us. Ford exemplifies this when he develops his airport-analogy further and thereby exposes its absurdity:

> To arrive at the number of atoms in a cubic centimeter of water (a few drops), first cover the earth with airports, one against the other. Then go up a mile or so and build another solid layer of airports. Do this 100 million times (Ford 1991, 22).

Of course, to imagine our solar system filled up with airports is just as impossible as imagining the number of atoms (all 10^{16} of them) in a cubic centimeter of water. It also does not help to be told that "if the airport-construction rate were *one million* each second, the job could have been finished in the known lifetime of the universe (something over 10 billion years)." All these descriptions say the same thing, namely that we cannot imagine these magnitudes or sizes. All scientific knowledge of relative sizes, all technical control does not yield a sense of absolute size, except to say that this or that is "incredibly small."

There is nothing surprising about this failure from a Kantian point of view. What is all the more surprising, therefore, is that we keep trying. Kenneth Ford demands that we "must make a real effort of the imagination to relate these new frontiers to the ordinary world"—why must we?

Intractable Agency

For the purposes of scientific understanding we do not ordinarily need to represent the size of things—indeed, science probes from within the limits of theoretical understanding and thereby fosters a sense of curiosity and wonder at that which remains unexplained: It is thought to be marvelous even that all the mechanisms identified by science are actually taking place in and around us.[19] We arrive at these moments of wonder when we run up against the limits of what we can imagine. And where this is not marvelous, we can safely refrain from imaging or imagining it. (So, you don't think that it is marvelous that your body is host to millions and millions of incredibly tiny parasites? Don't imagine it then!) Science aims for explanations of interesting perceived regularities, and only the most zealous of scientific realists care whether the unobservables that occur in these explanations correspond to anything real.[20] In daily life and for purposes for acting successfully in the world, there is no need for complete scientific understanding. This holds also for the probe microscopist who understands the theories of probe microscopy, who moves, even feels individual atoms, but who does not and cannot imagine the smallness of those atoms.

In contrast, we are obliged to form representations of our deliberate actions in the world. Where humans act purposefully, these actions are set off from the unconsidered or black-boxed background environment in which these actions unfold. Whether one thinks of technology as applied science or of science as applied technology, technology is purposeful intervention in the world. We therefore ought to develop a representation, no matter how impoverished, of how the technology works. If we fail to do this, this is a failure not only of imagination but also of morality or responsibility. Günther Anders' work is an indictment of just such failure:

> *The reach of our responsibility extends as far as the immediate and mediate effects of our actions, our omissions, or our deeds.* At least we should try to extend it this far and to assume the magnitude of that which we bring about in the world...Today's "*malum*" is essentially different from that which has dominated the European tradition, namely the Christian conception of "evil." ...*What makes us bad is that as agents we do not measure up to the products of our*

> *deeds...The gap* is therefore not that between mind and flesh but *between product and mind*. Example: We can produce the bomb. But we appear to be incapable of imagining what we have become as owners of our products and what we can do and have already done as their owners…This difference is unique in history, and thus unique also in the history of ethics…Due to this being a failure of the imagination, what is "weak" here is the "mind" (Anders 1972, 34-36).[21]

In the case of absolutely disproportionate effects[22] and in the case of technological agency absolutely below (or above) thresholds of human perception and imagination, to keep up with the effects of one's actions involves the effort to imagine the magnitude of things. Where we must engage in this effort and must by necessity fail, we are confronted with *noumenal* technology. While the case of nuclear arm signifies the abandonment of the effort and thus a moral failing from the very start, the case of nanotechnology is characterized by the persistent pursuit of the unattainable goal to imagine the unimaginable; it thus expresses a moral ambition to take responsibility beyond the human capacity to responsibly track the consequences of technical intervention.[23]

As we saw, for purposes of scientific understanding there is no imperative to imagine the size of things. For the purposes of taking responsibility for technical interventions, this depends upon the specific character of the technology and whether or not it is *noumenal*, engaging us in an impossible feat of the imagination. And this specific character is determined in part by our beliefs regarding the causal agency of the technology.

Desktop computers, for example, are clearly not *noumenal* even though we cannot represent to ourselves the speed and complexity of operations, let alone the site or spatial and temporal extension of a particular inferential step. We can black-box these particulars and are left with a device that relates macroscopic inputs to macroscopic outputs. In contrast, ambient intelligence, distributed or ubiquitous computing may well become a *noumenal* technology as this technology creates a quasi-natural, though now "intelligent" environment that structures human action without transparency and individual control. In this case, when we black-box the unimaginable we are left with nothing, but a nothing that somehow acts upon us.Whether radios, cellphones, or fluoridized drinking water are *noumenal* technologies depends entirely on whether one believes that fluor is an "active ingredient" or that radio waves produce environmental effects. Regarding the radio, for example, we are told and for the most part believe that it is controlled by its switch, that its use is closely coupled to our representations of how to manipulate power and volume, and how to seek out stations. At the same time most people hold that the pervasiveness of radio waves serves only as a passive medium that enables the tansmission of signal, and therefore we do not ordinarily imagine these waves along with the macroscopic device that is subject to our control. What defines opponents of cell-phones or of fluoridization is that they view these same technologies as being *noumenal*. They insist on the need to imagine unimaginable effects and are therefore prone to discern a vaguely generalized danger which blends in with and contaminates the background effects of nature itself (water, air, soil).[24] For them, these pervasive technical interventions change the things-in-themselves, the world not as we know it but where we rely on it unknowingly. This view is reenforced rather than weakened by the fact that we have no sensory experience of these pervasive changes.[25]

This same ambiguity applies to genetically modified foods as the paradigm case for *noumenal* technology. It is the paradigm case because the technical intervention remains essentially inconspicuous to human senses as well as natural selection. The genetic modification may produce visible as well as invisible phenotypic traits, and these phenotypic traits whither away or become consumed. However, the genetic modification may also persist and continue to act as it passes through our bodies to some untraceable place in the environment. Here, there is no represented proportionality between intervention and effect. Largely due to the smallness of the intervention, the effect is thought to escape our attention and control, meandering on indefinitely, perhaps producing a surprising large effect when and where we least expect it.[26] Finally, little reassurance comes from reading up on genetic engineering. The more we learn to understand and even admire its technical capabilities, the less transparent the world becomes for the individual consumer of genetically modified foods and the harder to maintain a sense of ownership, empowerment, responsibility, and control. Genetically modified organisms appear uncanny because they operate like nature itself. We can learn how they work, in principle, but we cannot know for any particular genetic modification where, when, and for how long it acts. All the while, however, it is easy to understand why it is that not everyone defines genetically modified foods as an uncanny, *noumenal* technology that necessarily implicates us in a failure to responsibly track its workings. Many scientists deny, after all, that the genetic modification should be considered biologically active. If its action exhausts itself and terminates in a single phenotype that is otherwise a plant or animal like all others, there is no need to imagine or take responsibility for the modification. In that case, we would simply take responsibility for creating the macroscopic phenotype and thereby remain within the bounds of phenomenal technology.

Similarly, while the effects of a nuclear worst case scenario exceed by far our imaginative capacities, the "normal working" of nuclear technology is not necessarily uncanny. Though we cannot imagine the size of the nuclei of uranium and plutonium, nuclear weapons or reactors are perfectly macroscopic parts of our ordinary world of experience, operated by switches, interfaced through output devices and monitors, relying on a lot of scientifically described, though for the most part black-boxed knowledge of physical mechanisms. As with our desk-top computers, it is irrelevant for questions of responsibility and control just how big or small the smallest components of a nuclear plant or nuclear weapon are. Significantly, however, the most troubling or uncanny aspects of nuclear technology concern the possibility that it might revert to quasi-natural conditions. First among these is the fear of accidental nuclear war as complex systems begin to "act on their own." This further amplifies the gap between the smallness of the occasion and the unfathomable magnitude of the effect (see Anders 1972, 89). Related to this is the fear of a decision-maker gone mad or the fear of radioactivity as an invisible, yet persistent and pervasive source of environmental contamination.

The discussion so far leaves quite open whether or to what extent nanotechnology will assume the character of *noumenal* technology. Nanostructured surfaces, material properties, or components in larger devices do not amount to *noumenal* technologies. When we black-box the incredible tininess of nano we are left with a sufficiently rich conception of how these operate and what it means to take responsibility for their mostly mundane effects. Freestanding nano- to microscale devices such as sensors and distributed components of networked computers are far more likely candidates for *noumenal* technologies, depending also on whether or not other technologies will allow us ultimately to detect, monitor, and track these devices. Of course, any device with biological properties, such as artificial bacteria for environmental clean-up can be considered *noumenal*, as would the legendary assemblers and nanobots of whom hardly anybody believes as of yet that they will actually come to pass.

The Meanings of Failure

By way of conclusion, it is now possible to identify the deeper significance of the apparently pointless attempts to illustrate again and again the smallness of a nanometer.

From a theoretical point of view, atoms and molecules are phenomena. Indeed, theories are the instruments by which we learn to know things that we cannot know as they are by and of themselves. With the help of theory, science makes images of things, stabilizes them in experiments, and creates models to exhibit them. The deliberate use of theory serves to remind scientists that they are creating certain kinds of pictures; it marks these pictures as aides to the imagination. From the point of view of theory, then, it is as a matter of course that these pictures stay within the bounds of imagination and do not convey any true reality of absolute size or the like. The repeated failure of visualization or illustration thus serves as a meaningful reminder of the reliance on scientific theory to establish patterns of relatedness among phenomena. Accordingly, that we cannot imagine the size of molecules is no problem at all: The hapless stories about the incredible tininess of nano underscore that the business of science is to relate things to one another and not to grasp an absolute reality. By dramatizing inconceivability, science highlights the unbridgable difference between *noumena* and represented phenomena and sides emphatically with the latter.

From the technological point of view, however, these hapless stories have a different meaning in that they strain to accomplish something that needs to be accomplished even where we lack the theoretical and imaginative resources to do so. It is a virtue of theory that it marks the impossibility of moving from scientific representations and how we imagine things to reality as such. Technical interventions, however, engage reality. The moral ambition to keep up in thought with the reach and workings of our technical interventions does not respect limits of knowledge if the interventions themselves reach beyond these limits. The ritual of attempting to illustrate the size of a nanometer thus serves as the constant reminder of an insoluble dilemma.[27] It is an expression of the moral ambition to take responsibility for nanotechnogy, and its failure demonstrates that some technologies systematically outpace our moral ambition. The exhibition of our failure of imagination thus dramatizes meaningfully the challenge and moral demand to reintegrate *noumenal* technology within the spheres of reason, responsibility, and control.

It is therefore not at all pointless to try what cannot be done. The ritual of repeatedly failing to imagine the smallness of a nanometer reveals the *noumenal* character of at least some envisioned nanotechnologies. Such "freestanding" nanotechnologies that are thought to act below the thresholds of perception and responsibility, provoke a mixture of abhorrence, awe, and fear that does not fit into the calculus of rationality. One of our oldest and perhaps deepest fear is the fear of brute, arational nature that has not been cultivated, rationalized, tamed, domesticated.[28] If an advance in technical control produces a type of technology that eludes sensory perception and human responsibility, this technology turns out to be regressive in that it casts us back into a state of nature. We cannot trust a *noumenal* technology. In order to earn our trust the various nanotechnologies will have to move beyond the incredible tininess of nano to become credibly integrated with human experience.

References

Anders,G. 1956. *Die Antiquiertheit des Menschen*. München: Beck.

_____. 1972. *Endzeit und Zeitende: Gedanken über die atomare Situation*. München: Beck.

Baird, D. 2004. *Thing Knowledge: A Philosophy of Scientific Instruments*. Berkeley: University of California Press.

Bensaude-Vincent, B. 2004. *Se libérer de la matière?Fantasmes autour des nouvelles technologies*. Paris: Institut national de la recherche agronomique.

Böhme, G. 1993. *Am Ende des Baconschen Zeitalters: Studien zur Wissenschaftsentwicklung*. Frankfurt: Suhrkamp.

Cleland, A.N. 2004. "Carbon Nanotubes Tune Up." *Nature* 431 (September 16), 251-252.

Eigler, D. presentation at the conference *Images of Science*, Amsterdam, December 7, 2004.

Ford, K. W. 1991. "The Large and the Small." in Timothy Ferris (ed.), *The World Treasury of Physics, Astronomy, and Mathematics.* Boston: Little, Brown.

Gamm, G. 2000. "Technik als Medium." in *Nicht Nichts.* Frankfurt: Suhrkamp, pp. 275-287.

Heidegger, M. 1977. *The Question Concerning Technology, and Other Essays*. New York: Harper & Row.

IWGN (Interagency Working Group on Nanoscience, Engineering and Technology) 1999. *Nanotechnology—Shaping the World Atom by Atom*. Washington: National Science and Technology Council.

Joy, B. 2000. "Why the Future Doesn't Need Us." *Wired* (April 2000).

Kant, I. 1997. *Critique of Pure Reason*. Paul Guyer and Allen Wood (translators & eds.) Cambridge: Cambridge University Press.

_____. 2000. *Critique of the Power of Judgment*. Paul Guyer (translator and ed.) Cambridge: Cambridge University Press.

Merchant, C. 1980. *The Death of Nature: Women, Ecology, and the Scientific Revolution*. San Francisco: Harper & Row.

Nordmann, A. 2004. "Nanotechnology's Worldview: New Space for Old Cosmologies." *IEEE Technology and Society* 23:4.

Ropohl, G. 1991. *Technologische Aufklärung: Beiträge zur Technikphilosophie*. Frankfurt: Suhrkamp.

Sazonosa, V. *et al.* 2004. "A Tunable Carbon Nanotube Electromechanical Oscillator." *Nature* 431 (September 16), 284-287.

Schäfer, L. 1993. *Das Bacon-Projekt: Von der Erkenntnis, Nutzung und Schonung der Natur*. Frankfurt: Suhrkamp.

Schummer, J. (forthcoming). "Gestalt Switch in Molecular Image Perception: The Aesthetic Origin of Molecular Nanotechnology in Supramolecular Chemistry." *Foundations of Chemistry*.

Soble, A. 1997. "In Defense of Bacon." in Noretta Koertge (ed.), *A House Built on Sand: Exposing Postmodernist Myths about Science.* Oxford: Oxford University Press, 195-215.

Stein, R. 2004. "Towards a Process Philosophy of Chemistry." *Hyle: International Journal for Philosophy of Chemistry*, 10:1, 5-22.

Weber, M. 1988. *Gesammelte Aufsätze zur Wissenschaftslehre*. Tübingen: J.C.B. Mohr.

Wittgenstein, L. 1922. *Tracatus Logico-Philosophicus*. London: Routledge and Kegan.

_____. 1997. *Philosophical Investigations*. Oxford: Blackwell.

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[2] Among Kant scholars, there is some debate as to whether *noumena* and the things in themselves should actually be equated. Whether or not there is a subtle distinction to be made here, does not affect the following discussion.

[3] Cleland's editorial comments regard a finding by Sazonosa *et al.* 2004. The authors of that paper refer in their abstract to "guitar-string-like oscillation modes of doubly clamped nanotube oscillators." Neither paper includes the now-popular picture of the "nano-guitar."

[4] Though Bacon did not coin the phrase, he has become powerfully associated with it as the founder of modern science by Merchant (1980), Böhme (1993), Schäfer (1993), compare Soble (1997).

[5] Heidegger (1977) offers an account according to which technical control presupposes a causal picture of the world, one in which actions either poetically bring forth what lies dormant or instrumentally exploit a scheme of means-end relations.

[6] For the notion of *Technisierung der Natur* (nature taking on the character of technology) see, for example, Ropohl (1991, pp. 70ff.) Here, nature is considered in terms of machines or literally rendered machine-like in order to assimilate nature to culture and to the spheres of knowledge and control. In contrast, *Naturalisierung der Technik* (technology naturalized) considers nature an engineer for the purposes of conceiving technology as natural. The latter strategy was identified, for example, in Nordmann (2004, pp. 52f.)

[7] Compare Kant's *Critique of Pure Reason*, especially pp. A 236-260 (B 294-315) where "*noumenon*" is defined as a problematic concept, that is, as a concept which contains no contradiction and is yet empty in that there is no means by which its objective reality could be

ascertained (A 254, B 310, compare A 252). There is no contradiction in assuming that there are "things in themselves" of which we only experience (phenomenal) appearances. But there is also no means to ascertain the objective reality of anything except by the way in which it appears to us. To posit the "thing in itself" as beyond and in some sense prior to human experience (as brute nature) involves no contradiction but also does not allow us to speak of the "thing in itself" as if we could know anything about it, including that it exists.

[8] One cannot argue, for example, that chemical change has a "deep structure" which is *noumenal* and that chemistry as a science should attend to this structure, see Stein 2004, especially note 1. If something can be conceived as a possible object of scientific experience, it is not *noumenal*. To be sure, the fact that process is not now the subject of chemical thought may reflect the conditions of possibility for chemical experience—whatever is meant by "process" may not be intelligible, especially if it involves a notion of transmutation that violates conservation principles. If this were the case, there can be no knowledge of such processes, scientific or otherwise, and the notion of chemical process would then serve, at best, to elucidate the limits of chemical knowledge.

[9] It will become clear, however, that only a small and perhaps insignificant part of actual nanotechnology research concerns technologies that *act* at the nanoscale. The argument does not apply to the more familiar applications where nanostructured materials serve as a substrate or medium for macroscopic action—as in the case of a macroscopic desktop computer that includes nanostructured components, for example.

[10] I would like to thank Jean-Pierre Dupuy for drawing my attention to this.

[11] Anders developed the distinction between *Vorstellen* and *Herstellen* in Anders (1956). He repeatedly placed it in the context of Kant's philosophy: Kant's critique has shown how our intellectual capacities are limited but the possible effects of nuclear weapons cannot be accommodated within the limits of the human condition but transgress or exceed it altogether (see Anders 1972, pp. 33f., 38, 73).

[12] See also Bensaude-Vincent (2004). Gamm, to be sure, takes his thesis about technology as a medium to be more general than suggested here. With Bensaude-Vincent I would like not only to distinguish the peculiar characteristics of such *noumenal* technology but trace how different technologies come to be no more than an intractable medium for human action. *Pace* Bensaude-Vincent, I insist on "*noumenal*" as opposed to "immaterial" technology because—unlike rituals, bureaucratic procedures, or social codes—the "nano"-dimensions of nanotechnology are not thought to be immaterial but, more fundamentally, fail to become material by failing to become an object of experience at all.

[13] Compare the discussion of Bill Joy's "Why the future doesn't need us" (Joy 2000) in Nordmann (2004, 50).

[14] "The Incredible Tininess of Nano" is the heading of a section in IWGN (1999, 3). I am taking this heading literally: The tininess of nano is not just amazing but incredible - impossible to be known, believed, or imagined. Of course, the brochure goes on to ask of us what cannot be done, namely that we imagine this incredible tininess.

[15] Don Eigler during a presentation at the conference *Images of Science*, Amsterdam, December 7, 2004.

[16] Wittgenstein (1997, remark 50): "There is *one* thing of which one can say neither that it is one meter long, nor that it is not one meter long, and that is the standard meter in Paris—But this is, of course, not to ascribe any extraordinary property to it, but only to mark its peculiar role in the language-game of measuring with a meter-rule."—To ask how long a meter is would be akin to asking what "being" is. The verb "to be" serves the grammatical purpose of predication, the terms "meter" and "nanometer" belong to the grammar of measuring, that is, of establishing commensurability among things within a given or among different size regimes.

[17] Similarly, it has been suggested that we can imagine a billionth (10^{-9}) of something else because our experience ranges across 10^9 orders of magnitude from millimeters (10^{-3}) to 1000 kilometers (10^6). However, even if we could therefore imagine the relation of 1 millimeter to 1000 kilometers (along the lines of imagining a basketball in JFK airport), we could not therefore transfer that imagined relation to the different relation of one nanometer to a meter.

[18] See the brochure *Große Chancen im Nanokosmos—Nanotechnologie in Hessen*, 2004 (the brochure takes Frankfurt-Kassel as the distance of reference).

[19] Philosophical expressions of this wonder include Kant's introduction to the *Critique of the Power of Judgement* and Wittgenstein's "not how the world is, is the mystical, but that it is" (Wittgenstein 1922, remark 6.44).

[20] For science and the search for explanatory accounts, it is heuristically useful to assume their real existence. In the course of scientific research, the unobservables become real for all practical purposes of experimentation and instrumentation. But this is true, of course, also of "magical" explanations: If I tell myself that the room has been cleaned by fairies, I assume—of course—that they must really exist since otherwise they could not have performed such a tangible feat.

[21] The novelty of this ethical situation is therefore that it is not the flesh that is weak: "the element of 'nature' that up to now always contributed to a definition of the '*malum*' drops out of the picture."

[22] "*End of the Comparative*...but what is supplied *transcends* our needs, it consists of things that we *cannot* desire; it is *absolutely* too big" (Anders 1972, 99).

[23] This moral ambition finds expression also through early engagement with ethical, social and legal aspects of nanotechnology.

[24] See Todd Haynes's 1999 film *[Safe]* as an excellent analytic case study of the perceived uncanniness of such and similar technical systems.

[25] I am here focusing on smallness but it is worthwhile to extend the argument to large and even just largish technologies. (To be sure, ambient computing or radio technology should be considered not simply for the invisible smallness of their physical implementation but also as large technical systems.) For example, should we consider as an example of *noumenal* technology the fully automated climate control of an office building, if only because it cannot be surveyed or controlled by individual users?

[26] This description may not be true to GMOs as we know them. But it captures why this technology is thought by many to be so uncanny.

[27] It would be far too simplistic to introduce a variation on the Kantian theme of phenomena vs. *noumena* by associating on the one hand science with nature and the deterministic representation of phenomena, on the other hand technology with freedom and the expansion of our action as free, rational and responsible (noumenal) beings in the world. This move interprets "*noumena*" primarily in terms of human freedom (rather than in regard to unknowable things in themselves as limits of knowledge). The insoluble dilemma would thus be associated with the Kantian dilemma that we are free only as *noumenal* but causally determined as phenomenal beings. If we were to follow this suggestion, *noumenal* technology would be technology unadulterated. This contrasts starkly with my suggestion, however, that *noumenal* technology is regressive and tends to diminish human autonomy in that it withdraws from the mastery of nature by giving technology the character of uncomprehended nature.

[28] Baird (2004) and the history of nanotechnology remind us that these four terms should not be equated: by stabilizing phenomena through intuitive knowledge and control of system behaviors technology can "tame" nature without therefore "rationalizing" it. Just to the extent that this is true, however, we are confronted with the problems described in this paper. Indeed, the demand that *noumenal* technologies be integrated with human experience is premised on the notion that sensory experience and a "feeling" for the technical intervention are sufficient to place the technology into a framework of deliberate and responsible human action.

When is an Image Not an Image?[1]

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The challenge is to tell the truth. In the world of nano this is not as easy as it sounds. Take, for example, the question of images claimed to represent what some nano confirguration or another looks like. It is alleged Scanning Tunneling Electron Microscopes (STEMs henceforth) produce such images. Let's rehearse what happens: According to Rasmussen and Hawkes:

> …an electron beam that is small compared with the imaged area passes over the specimen in a regular pattern, and a picture of the specimen surface is reconstructed on a video tube…interaction of the beam with the specimen produces varying intensities of backscattered and secondarily released electrons for each position in the scan, and these are registered by a detector placed appropriately near the specimen…All electron microscopes depend on the capacity of magnetic and electric fields to alter the path of electron beams according to the laws of optics (1998, 383).

Using an STEM is one of the ways it is said that we can see what is going on at the nano level. However, I am suspicious. Or, to put it in a less antagonistic way, to accept this claim will, I believe, force us to expand or change our understanding of what it is to see something, and in this case in particular, to understand what constitutes an image. There is nothing wrong with this. The meaning of words do change over time—they often expand, as the meaning of "men" in "All men are created equal" has expanded to include African Americans, other minorities, and women. However, we often do not pay attention to the fact that while we continue to use a word whose meaning we think we understand, in this instance "see" and "Image", we also sometimes extend the meaning of that word by applying it to novel situations where they only apply at best metaphorically, as I argue below. Eventually what is at first a metaphorical extension of the meaning of a term may become an accepted part of the meaning of the term, but we should be sensitive to the fact that the meanings of words change over time. This claim is part of a more general thesis I am developing: to explain what we are doing when we employ novel instrumentation, we often employ words whose meanings we already understand in an effort to characterize the sort of thing we think we are now doing with this new instrument, despite the fact that seeing through a microscope is not the same as opening one's eyes and seeing a tree in front of me, if we are to adhere to a strict sense of "seeing". I argue elsewhere that in extending the meaning of words metaphorically we also change the meanings of the family of concepts with which they are associated, such as evidence and explanation.[2]

If we take Rasmussen and Hawkes seriously, what the electron microscope does is to produce an image. But, I suggest, this is unintuitive for the reasons given below. Furthermore, to claim that an image is produced, suggesting by that that the image is a genuine and *realistic* representation of what is really there, has serious ethical and social consequences. I want to talk about images first, and then I will turn to some of disturbing consequences of thinking about "seeing" by way of an STEM.

Imagine if you will, a very accurate tennis ball machine. It is a device that shoots tennis balls at you so you can practice returning them without having a serving partner. Lets assume you take this machine and aim it at a wall built from rough hewed stone. Your job is to construct an accurate representation of the surface of the wall simply by observing the directions of the balls as they bounce off the wall. Well, clearly you need some help to do this. You need to know a lot about the physics of objects colliding and how irregular surfaces change the vectors, etc. You also need to know a lot about translating what you see happening to the balls after they collide with the wall onto paper in a way that captures not the picture of the ball shooting off in this direction and then that, but the texture of the surface of the wall. It is not as if you are directly drawing what you see when you look at the wall. You are interpreting the action of the balls as indicating something about the surface and then you are putting that guess down on paper. That, with some minor modifications, is what the alleged image produced by an STEM is supposed to have accomplished. But instead of a person doing the drawing, a computer program does it. And, we are asked to consider the result an image of the surface. Take your hand, if you will, and run it over your shirt. Now draw what you felt. It is not easy is it? That is why I am asking this question, "when is an image not an image?"

Let us begin by trying to figure out what an image is. This is not an easy task, for we tend to use a substantial vocabulary of what we often take to be more or less synonymous terms when talking about what STEMs produce. Thus, there has been a lot of loose talk about images, representations, etc. Terms like these have been casually interchanged, mangled and generally semantically violated. I will not claim that I offer much of an improvement—but I at least want to alert us to the problem of image talk. In cases like this, my preferred method is to work our way toward a common sense understanding of what ought to count, in this case, as an image.

My intuitions tell me an image is a representation—where a representation is the result of an attempt to capture the salient features of an object, scene, state of affairs, or idea, etc. Fortunately or unfortunately, what constitutes a salient feature is a function of the person or persons constructing the image. As a first pass, consider the following items as images:

- Sculptures
- Photographs
- Portraits
- Still lives
- Landscapes
- Various kinds of drawings
- Motion pictures—both animated and "realisitic"
- Visualizations inspired by poetry
- Visualizations inspired by music
- Plays
- Operas
- Ballet and interpretive dance

If we accept the fact that these are images, then a Picasso such as the Gernica counts as an image, but it would seem that a Jackson Pollack does not only in.so far as it is unclear what a Pollock is supposed to represent.[3] This entails declaring that to be an image is to be representational. But it says nothing about what makes something representational. That said, nevertheless, it is not shocking to note that not all paintings are images, where a painting is nothing more conceptually complicated than paint deliberately applied to a surface. But, if it is true that not all paintings are images, especially when they are not representational, have we not found a way into our topical question, when is an image not an image? It looks like we could reasonably say that an image is not an image when it is not representational. On the other hand, doesn't that just beg the question? After all, it isn't at all clear that for an image to be an image it must be an image of something. When you think about it, on the one hand, it seems arbitrary to demand that images be representational, but, on the other hand, to do so seems to beg the question. For example, consider the following as candidates for being added to the list above.

- Diagrams
- Flow charts
- Data tables

The interesting feature of these sorts of things is that while they are not representational, they do convey information in visual form. For, on the surface at least, it seems as if these forms of images have a different semantics than written language. The important point however, is that they do seem to have a semantics, for they do manage to convey information. The unresolved problem that remains for us is how to determine if the image is an accurate representation. So, if we accept this approach, then one answer to our question is that an image is not an image when we do not know if it is representational but conveys information none-the-less.[4] With your permission, let's accept that for the time being as a first pass.

However, that just moves us back one step, for now we can re-ask the question that our quick look at electron microscopes motivated: when is an alleged representation a representation? The point here is epistemological.

I think it not too radical to suggest that seeing is a complex activity in which after learning to see that as a tree or as a car, we forget that we had to learn that. In our mature state we see the world around us and assume we see it for what it is. That is why philosophical questions like "but are you seeing what is really there?" seem so silly. But, on reflection, we also understand that seeing is an interpretive process and that we bring to our seeings a load of background information and experience. Elsewhere I have argued that to call it a seeing by way of images generated by an electron microscope is a metaphorical extension of our common sense notion of seeing (Pitt 2005). But, I have now come to realize that there is a lot involved in appealing to metaphor here. If we unpack it, as I would like to start to do here, we can see that to understand through metaphor is to do a number of things at once. First, we use metaphor to access what is new and different because in a metaphor we take what we know and apply it to the unknown and say that the unknown is like the known in these various ways. It makes the new seem familiar and approachable, usually. Sometimes, as in the example of the tennis gun above, it makes the unknown or the new seems even stranger than we first thought. Second, when using metaphor to make the new and unknown approachable, we are also asked to accept that certain things that we do not really understand are reliable. Metaphors tell you this is like that in certain limited ways, and by the way, just accept that everything else is working just fine, however that happens. In the case of the electron microscope, when asked to accept what it produces as a representative image, we are also asked to accept the fact that the assumptions built into the manner in which that image is constructed are correct and reliable. To use the language of science studies, we black-box the process and merely look at the result. But to call the image created by the electron microscope an image is to ask us to accept in some fundamental way that the science is sound and the technology (programming?) reliable and the people manipulating it reliably are honest.

But, I suggest, this ought to be a lot to ask. What is interesting is that it appears that it is not. It is a measure of the success of the scientific establishment that we, the general public, tend to accept claims based on the use of increasingly complicated instruments working in the realm of the frontiers of science with increasing readiness. That is, the more complicated the science and the more simplified the public explanations, the more readily we tend to accept those fantasies. That is why it is important to know what really happens in an electron microscope before buying into the claims with which it is associated. Before I explore what that ominous sounding remark is supposed to suggest, let me give you just one example of the kind of phenomenon to which I am referring. I think we are all in awe of the images sent to us by the Hubble Space Telescope. The ones of the horse head and crab nebulae are just breathtaking—and the colors are truly inspiring—just one catch—the colors are computer generated. When I tell my students that, the looks on their faces resemble the one when they learned that there is no Santa Claus. What got me going in this direction was a presentation at the Conference, "Discovering the Nanoscale" at Darmstadt in October 2003 that revealed that the picture of the nano-scale IBM was not just constructed through the assistance of computers, but it too was computer enhanced—with the colors added, for example. This, it turns out is a pervasive problem; even the choice to use grey scale is a decision to create the image in a certain way. So when we say of an image that it must convey information, should we not also be asking (1) whether there is a claim that reality is being representing, and (2) is the image presented of something real or imagined? Perhaps, then, should we not be asking this slightly different question: "When is an image *not* an imagining?"

The issue here is both epistemological and ethical. The epistemological issue concerns, for lack of a better term, noise. We are familiar with the problem of filtering out noise when searching for an identifiable signal. The problem is multi-faceted: what to filter out and on what criteria, what to amplify, to what degree, etc. The problem with color-enhancement and sharpening up of nano-images is that we don't yet know what is important and what is not. Further, the problem may become intractable since we do not have a god's eye view from which to determine if we have it right. In a certain sense then the problem here is an *in principle* lack of access, or to put it differently, a case of very strong underdetermination. But is this really a problem? We have in-principle-lack-of-access to many astronomical events, like the big bang, and we still claim to know a lot about the early universe. We have images from the Hubble of far distant galaxies that we can never get close to in person, and yet we can still understand a lot of what is going on there—or so we think.

My worry is that, unlike the "images" from the Hubble, we have relatively little experience in enhancing the images produced by STEMs. We have ways of checking up on the Hubble images. For example, we can experiment with filters and use smaller telescopes here on earth to check out their effect when we look at mountains or trees. However, although we have lots of experiences with so-called images from STEMs—we do not have such successes in fixing them up. This is, in a curious way, a new version of the what-are-we-going-to-do-when-we stain-a-specimen-that-we-are-going-to-examine-under-a-standard-miocroscope problem (see Pitt 2005). Computer enhancement of images is fun, especially with all the nifty colors we can use. But is it producing an honest replication of the object/surface in question? Clearly not, and that raises the ethical issues.[5]

The ethical issues arise in two forms: strong and relatively minor. The relatively minor issues have to do with the relationships between science and the public. For example, we are misleading the public when we fail to disclose fully what we are doing when we computer enhance our electron microscope constructed images. The strong ethical issues center around the fact that these images raise false expectations. Among them, that we know more than we do. The presentation of these beautiful pictures suggests in a very strong way that this is indeed what it is like out there, in there. But more importantly, they mislead in crucial ways. The beautiful computer simulations we see of nano interactions are not only beautiful simulations, they are also almost heart-stopping in their ability to feed the hubris we sometimes exhibit when employing the newest technological toys, computer and advanced programming techniques, among them. Please do not get the wrong impression—I am not suggesting that we should not employ the latest technologies in science. What I am talking about is the illusion we create not just in the general public but sometimes in the practicing scientific community. The illusion is that we know more than we really do. Never underestimate the ability of human beings for self-delusion. These computer generated and enhanced pictures suggest that the world is at rock bottom a simple place. It can be pictured as individuals atoms resting on stable fields that we can manipulate at will, twirl them, enlarge and narrow them, put them to music, make them dance, when in fact nothing of the kind is the case. The world at the nano and quantum mechanical level is a buzzing, shifting, constantly in motion in non-linear and non-classical causal fashion.

This is all heading in one direction. It is not just misleading to suggest that the world is simple at the bottom. It is epistemically suspect. It employs a crucial but faulty assumption. It is the assumption that the world is better understood if we simplify our presentations of it. I humbly suggest that this is wrong-headed. It may in fact be helpful to extract some feature of the world, color it pretty non-natural colors and play with it. But it is more important to put that heuristically altered item back into the buzz and try to understand it in that environment, its "natural" environment. Most importantly it is crucial that we explain to the public and our colleagues the purpose of the heuristic move and what it reveals about what is really going on at the bottom.

So what is wrong with simplification? It suggests that we know more than we do and, crucially, that we can do more than we can. The scientific community has done a good job of convincing the public that it has god-like properties—but this situation presents a double-edged sword; the public feeds on gods that fail. Be honest about the mess and you will repeat positive rewards. Further, it is not the simplicity of the universe that makes it the object of our enquiry, it is the complications, the unanswered questions, the mess of it all. The more we look, the more complicated we find it to be. If you cuddle the public and give them simplicity and then in the crunch, when, for instance, in the hospital, you say, well it is more complicated than that, then you will have failed miserably. I love the pictures, but they are not representations. They are heuristic imaginings, extended metaphors, if you will, and they should be recognized as such and treated that way. How will that affect the way in which the work of science is perceived? My guess is that it will enhance it. Doing science is hard work. The public should know that and when they do the successes of science will be all the more appreciated. Telling the truth is also hard.

To conclude, let me summarize. The question is ”in what sense is a STEM computer generated picture of nano structures an accurate representation of what is there?” Following some discussion of how “seeing” using a STEM involved a metaphorical extension of the concept of “seeing,” It was argued that to be a representation the image must convey information. The problem is in understanding what the information is conveying, since we cannot directly access the domain that we are purporting to represent. The problem is not that we do not know how to interpret what is presented to us as an image, but, rather, that we have loaded the creation of the representation ahead of time without being able to know if our guess that this is what the STEM and its fellow traveler computer programs are producing is an accurate picture of what is really there. The reason why there is so much discussion of when an image is an image is that this really is a question of whether or not the image that is produced is an accurate portrayal of something that is really there or a mere fabrication.

Consider one last attempt to convey a sense of the magnitude of the problem. If we do a random sample of some domain and then plot the results in three dimensions, assuming that is sample is truly random and that there is no natural clumping of the data, which curve is the correct one? We can draw an infinite number of curves through those data. Without an independently certified decision procedure for selecting the correct curve we are simply left with the data. The problem is further complicated by the fact that there are ethical dimensions. (1) To say that this is what is taking place at the nano-level, is to lie, since we don't, in fact, know that to be the case. (2) To present these standard, nicely colored, enhanced, and simplified pictures as genuine representations of what is going on at the nano-level is to claim falsely that nature is in fact simple and clean and neatly colored at that level. But, nature is not neat and tidy at that level. To suggest otherwise is to mislead by way of making it appear that there are simple answers to very complex problems. That approach gets us into trouble at the political level and it should get us into equally big trouble in our epistemology.

References

Rassmussen, N. & Hawkes, P. 1998, "Microscope, Electron" in R. Bud & D.J. Warner (eds.), *Instruments of Science*. Garland Publishing.

Pitt, J.C. 2005. "The Epistemology of the Very Small" in A. Nordmann, J. Schummer, & D. Baird (eds.), *Discovering the Nanoscale*. IOS Press.

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[1] My thanks to Thomas Staley for his assistance. All mistakes are my own.

[2] This thesis is being developed in a book length manuscript under construction entitled tentatively, *Seeing Near and Far, A Heraclitian Philosophy of Science and Technology*.

[3] If turning to art is seen as somehow cheating, it is important to remember that the creation of images began in art.

[4] Yes, "information" is not defined. But, I suggest, we have to start somewhere. If we succeed in making progress by proceeding in the manner suggested we can always return and fine-tune the argument by going deeper into concepts like "information". Call this approach "conceptual boot-strapping".

[5] The "Clearly not…" might be considered contentious, but with a little expansion, I believe it will be obvious. Consider, for example, that the surface on which nano scale objects exist is at the

interface between the quantum domain and the atomic. We have no idea how to visually represent what happens in the quantum domain, so we cannot say we are accurately representing the surface on which the atomic structures we are picturing sit. If we cannot claim to be accurately depicting the surface, then how can be sure of the space in which nano structures function, and if that is uncertain, so must be our representation of the nano structures themselves.

Beyond Truth: Pleasure of Nanofutures

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Introduction

Ever since Ludwik Fleck's analysis of the role of popularization in the genesis of scientific facts, scholars have sought to explain the relation between science and the public in terms of truth, or the negotiation of truth (*e.g.* Shapin & Schaffer 1985; Latour 1987; Collins & Pinch 1998; & Shapin 1994). However, prompted by changes in the funding structures for science, researchers have themselves been turning away from a concern with truth, as in a scientific theory that matches the deep structure of the material world, and towards a concern with research relevant to a market. Along with this turn, the role of scientific discourse in the public sphere has changed. This paper probes pleasure as an appropriate conceptual term in addition to truth.

We should not be surprised by changes in the public sphere; Jürgen Habermas has shown it to have changed for centuries (Habermas 1989). I will discuss the changes taking place in the last few decades only. Habermas thinks in terms of human beings with differing standpoints who reach some level of consensus in the public sphere by actually communicating content to each other. The public sphere is a kind of forum where consensus is somehow reached with the use of reason. Pleasure is a decidedly non-rationalist aspect of the public sphere.

The linear model that has held sway for a long time after World War II is perhaps the most simplistic of all. According to this model, truth is created in the sphere of pure science and passed on to applied science and technology. Ludwik Fleck (1979) provided the first critique of this scheme involving a notion of feedback. Fleck used the terminology of the exoteric and the esoteric sphere, where the exoteric sphere is more public understanding of science than engineering—the point being that the esoteric sphere is not isolated. Fleck concerned himself only with this one boundary: between the inner sanctum of science and the outer lay world. However, Fleck was ignored until the 1970s when the linear model came under scrutiny. In Shapin's discussion of the public sphere, it was just this boundary of the expert and the layperson that was at issue (Shapin 1990). Since then Shinn and Whitley (1985) have denoted a more complex flow of information between various groups with various degrees of expertise that Bucchi (1998) has visualized. The funnel shape denotes theories and results being strengthened as they move towards the 'popular stage'—in Richard Whitley's terms:

> The more removed the context of research is from the context of reception in terms of language, intellectual prestige and skill levels, the easier it is for scientists to present their work as certain, decontextualised from the conditions of its production, and authoritative (Bucchi 1998, 12).

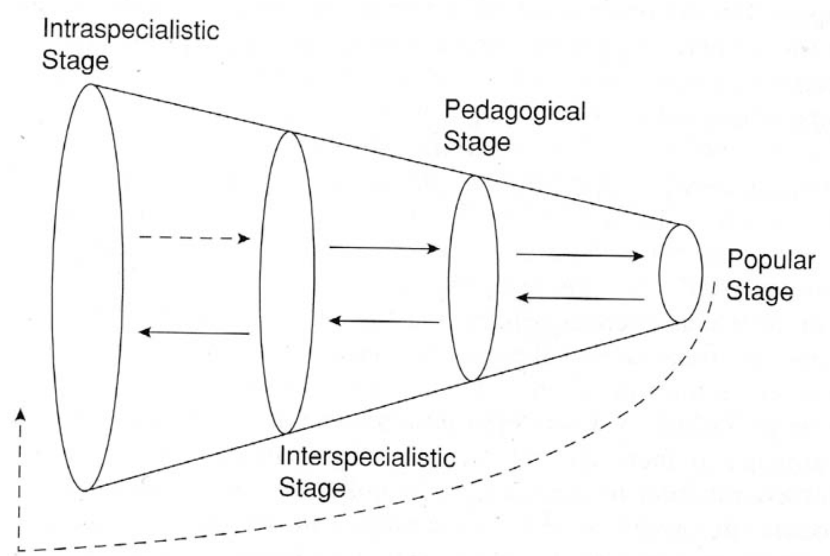

Figure 1: Bucchi's visualization of the public sphere

The intraspecialistic stage refers to specialist journals, such as *Physical Review*. The interspecialistic stage refers to journals intended for scientists from all disciplines, such *Nature* or *Science*. Textbooks constitute the pedagogical stage, and the popular stage might be thought of as TV programs, for example on the Discovery channel. Bucchi's main focus is on cases such as cold fusion, in which two researchers at the University of Utah held a press conference to announce their discovery, thus bypassing the intermediary stages (and thus also peer review) altogether. His focus is visualized with the bypassing large arrow.

Facts, truths, or knowledge is produced and passed around in this realm. It is clearly not just a one-way street going from the expert to the layperson. There is another large body of work that analyzes the way in which the expert's trustworthiness and credibility is built up, focusing on such issues as objectivity and authority. This was a major point of Shapin and Schaffer's *Leviathan* and it was taken up, for example, by Ted Porter's configuration of quantitative analysis as a technology of trust—a means of fortifying claims fending off charges of subjectivity or vested interest (Porter 1995). Daston and Galison (1992) have proposed a taxonomy of objectivity along with a periodization based on it. Hilgartner has focused on the important role of staging for the establishment of trustworthiness, in the process bringing together an increasing amount of literature on staging science. He analyzes science advisors' self-presentation and convincingly argues that "the theatrical perspective offers a means to examine how credibility is produced in social action, rather than treating it as a pre-existing property of an advisory body" (Hilgartner 2000, 7). This is a topic that Iwan Morus has devoted much attention to (Morus 1998). It is important for such experts to convey a good impression of their integrity and moral character in order to persuade.

All these studies are indispensable for our understanding of the role of science and the public sphere. It may well be that in the post-war period when the linear model held sway and professionals were generally revered, there was no need to consider other questions than the truth, and the trustworthiness of those who speak authoritatively about it. But in the last few decades the emphasis in science funding has moved away from a concern with filling in gaps of knowledge to the production of knowledge that is worthwhile or serviceable (the latter is Sheila Jasanoff's term). Knowledge has become more of a means to an end and less of an end in itself. This has put much more pressure on accountability. How does one ascribe value to research when the value only becomes visible at the end of a 20-year long commercialization process subject to the vagaries of the market?

Adapting to such funding realities, some scientists have turned to hype. The tremendous amount of hype surrounding nano or genomics is at least as important a part of science and the public sphere as the truth discourse is. None of the above authors pay attention to hype. I will argue that in addition to persuasion, and even suasion, science in the public sphere features also the feeling of exhilaration. This is not an indictment of scientists engaged in hype—after all they are only playing their cards well in the new game of science funding—it is merely an argument that while the truth discourse may have been appropriate at the time of the linear model, it is now wide of the mark.

Barthes' discussion of "writerly" and "readerly" texts may serve as a heuristic. Barthes discusses both texts for passive consumption and texts that stimulate the reader's active participation. The former may prompt pleasure (*plaisir*) and the latter a form of exuberant joy (*jouissance*). *Jouissance* calls up a violent, climactic bliss closer to loss, death, fragmentation, and the disruptive rapture experienced when transgressing limits, whereas *plaisir* simply hints at an easygoing enjoyment, more stable in its reenactment of cultural codes (Barthes 1975, esp. page 4). Barthes' *jouissance* may well resemble the feeling of exhilaration prompted by nanohype. But my main point is that pleasure, in all its shades, may be found in scientific texts—and also in images—and that it matters for the topic of science and the public sphere. It is not just about the fact-truth-knowledge-authority-expertise-objectivity-disinterestedness-credibility complex, but emphatically also about exhilaration, pleasure, hopes and fears.

A Case Study: From Surface Physics via CAMP to inano

Scientific texts and images are intended for specific audiences. Some audiences are homogeneous, for example those addressed in a textbook or at a specialist conference. Other audiences are more heterogeneous. Scientists sometimes address newspaper readers that might include scientists in neighboring scientific disciplines, high school students contemplating a scientific career, decision makers in funding agencies and tax-payers.

I will analyze the publications of a scientific group in the Physics Department of the University of Aarhus, in Denmark. This Danish group is interesting because it exemplifies the changes of science in the public sphere in the last few decades—to the point where all of Bucchi's stages are involved. The main character in the plot is Flemming Besenbacher, an entrepreneurial professor of physics at the University of Aarhus. He sits on a great many committees and is generally very attentive to the political work that needs to be done to keep the funding for a lab coming. Ivan Steensgaard, a Besenbacher colleague, has worked at Bell Labs and is very experienced at generating publications in peer-reviewed scientific journals. In contrast to Besenbacher, he focuses on just this one task. Steensgaard is content to produce high quality science in a lab and leave the dealings with the outside world to others.[1]

The entrepreneurial Besenbacher has been very successful over the last two decades in creating an infrastructure within which research and many individuals thrive. It started in 1986: The entrepreneur and the more narrowly focused Steensgaard worked in surface science (the Danish term, *overfladefysik*, translates directly to the even narrower surface physics) and were fascinated with the possibilities of the newly invented instrument, the Scanning Tunneling Microscope. They teamed up with a colleague, Erik Lægsgaard, a talented radio amateur who managed to build a basic STM simply using stuff lying around in various labs. For quite a while they spun off publications investigating surfaces with an STM. "Pay dirt," Steensgaard calls it: it almost didn't matter what you did with the STM, all results were interesting and illuminating.

In Denmark there had been a tradition of spreading the tax kroners evenly among all university departments with little pressure to account for the money spent. By the late 1980s, privatization of government institutions generated capital that was to be spent in a more "elitist" (the critics' term) fashion, by funding research centers in mutual competition and subject to much increased accountability (For an overview of the most recent developments in Danish research policy, cf. Lundager Jensen [1996] and Grønbæk [2001]). The grant was to run for 5 years in the first instance and could then only be renewed once—the "sunset clause". Renewal was dependent upon the number of publications, weighted by the status of the journal, but also upon social relevance of the research. Besenbacher networked with a view to economic and environmental relevance. He located it in two prongs:

1. Work in collaboration with a Danish company providing catalysts for chemical industries. Catalysis is of great commercial interests; for example, a catalyst speeding up a desired chemical reaction might save millions of dollars for chemical industries.
2. Work on de-sulfurizing catalysts promising a reduction in acid rain and general environmental improvement.

The group managed to get an extension to their grant, and so the Center ran for an entire decade, from 1992 to 2002. The Center was a success in a number of ways. It became a high-status destination for graduate students and post-docs; it raised the profile of Aarhus University; it paid salaries and expenses for many individuals; it generated some interest amongst private enterprises; and it successfully reached out to secondary education by providing projects for high school students.

By 2001 Besenbacher was worried, though. His institutional creation was about to get the axe because of the sunset clause. He fulminated against the inequity in the discontinued funding for his successful enterprise, when other kinds of staid, old-fashioned research had steady funding by default (albeit at a low level). He worked diligently behind the scenes to have the sunset rule changed, but to no avail. He had no choice but to develop a new project and compete with others to set up a new Center. Having his ear to the ground he cultivated relationships in medicine and the life sciences, thrashing out a Center to work on, *inter alia*, biocompatible materials using scanning probe microscopy. He was successful again and now heads up a new Center. The old Center was called CAMP: Center for Atomic-scale Materials Physics, a descriptive term understandable to other scientists. The name of the new center is Interdisciplinary Nanoscience Center, or iNANO. The name of the Center now is a tag intended for a larger audience than physicists, chemists, biologists, and medical scientists. Atomic-scale materials science would have been much clearer, much less ambiguous, to the academic constituencies but incomprehensible to the many others that also matter, such as government officials, members of parliament, journalists, newspaper readers, and high school students. The iNANO Center's own organization underlines the fact that discourse has to take place in a great many venues—one might say in all of Bucchi's four stages simultaneously. The Center's own pamphlet makes the point with a Venn diagram of its organization: three mutually intersecting circles of iNANO, Nanoschool, and Bachelor and Master Studies (basically research and teaching) are ringed by the institutional support: University of Aarhus; Aalborg University; Danish Ministry of Science, Technology and Innovation; Danish National Research Foundation; Danish Research Agency; Danish Technical Research Council; EU Framework Programs; Danish Natural Science Research Council; Industrial Partners. This list reveals with great clarity the many different audiences that iNANO has to contend with, the many stages for which texts and images have to be crafted.

Besenbacher has developed a much more involved publication strategy than the one involving Steensgaard. The Center now issues press releases, starting with sentences such as this: "This week, a group of scientists at the University of Aarhus has published an article in the world-leading scientific journal, *Science* magazine. With the use of a powerful microscope capable of resolving single atoms (a scanning tunneling microscope), the Denmark-based research group has discovered a new phenomenon..."[2] They also publish in various glossy magazines in the science popularization genre. Graduate students, such as Jeppe Vang Lauritsen and Anne-Louise Stranne, have been inducted into this kind of publication early on. Vang Lauritsen had several such articles under his belt before graduating. Both themes of social relevance, mentioned above (improved efficiency of chemical industries, and environmentally improved technologies), are at the focus of these publications. Besenbacher writes reports for various political bodies, both the local university and municipal administrations, and the national parliament. He sits on the Danish Natural Science Research Council (DNSRC), an advisory committee to the national parliament, the Folketing. This council has a dual task: administering a block grant for research and advising the Parliament on science policy. The committee writes reports and strategic assessments which, I presume, is the single most important text for decisions of a budgetary nature. The 2003 strategic assessment for the next four years reads like a carbon copy of the entrepreneur's views: Elite centers are to be funded, the social relevance is pushed, and the importance of training the next generation for industrially relevant research is presented as the lifeblood of the Danish economy. The specter of declinism is deployed: the countries Denmark usually compares itself against (the US, Sweden, Finland, the UK, Germany) are investing money in research, and the Danish standard of living is at risk unless sufficient funding, and so on.

It is worth noticing that one of 6 special strategic areas of focus is nano and that authors' conflict of interest is not discussed.

The future benefit is stridently formulated in this DNSRC publication. The future tense is consistently used where one might have expected a subjunctive. Nanotechnology *will* thus offer: pharmaceuticals without side effects dosed using nanostructures; smaller and faster components for computers and communications technology; new and better building materials; new batteries and energy storage systems; new sensors; lab-on-a-chip systems; optical nanostructures for ultra fast communications; biological manufacturing of materials; and new catalytic converters for environmental purposes and for energy technology. The summary of all this takes on an almost prophetic tone: "Nanotechnology is an important area that will form the basis of the next industrial revolution."[3]

Locating the Pleasure

I will argue that pleasure may be found in much of this discourse, primarily due to the exhilaration felt by contemplating a technologically enhanced future. The communication of this exhilaration is at times explicit in the texts, and I will argue that it resonates also in the images.

I will suggest the presence of such pleasure in all genres. I will first discuss newspaper articles, several illustrations of which turn up also in an iNANO pamphlet. I will then turn to the CAMP and iNANO websites that prominently feature STM movies. Finally, I will discuss an article in a peer-reviewed journal which utilizes such movies. In the course of this section I generally move from the right to the left in Bucchi's diagram, although much is clearly intended for several of Bucchi's stages simultaneously.

Newspapers and Pamphlets

In an article in the daily *Jyllandsposten,* Besenbacher displays three molecules: ribosome, bacteriorhodopsin, and molybdenum disulfide. The legends help us understand their meaning (Besenbacher 2002):

> The living cells contain fascinating nanomachines. The ribosome here is the cell's protein factory. Ribosome's atomic structure has been determined recently, also with the participation of researchers from the iNANO center.
>
> Nature is a decisive source of inspiration within nanotechnology. The bacteriorhodopsin shown here is a protein regulated by light. It works as a nanoscale pump transporting protons across the membrane encompassing living cells.

These two molecules are being represented as a nanomachine and a nanoscale pump, which is precisely the language pioneered by Eric Drexler, a mechanical engineer by training. Drexler's vision of nanoscale machines built atom by atom gained tremendous credibility with Don Eigler's images of IBM and atomic corrals written with xenon atoms and imaged with an STM (Hessenbruch 2004). And indeed, Besenbacher uses just this corral in the same article with the following comment:

> this image has developed into a symbol of the promise of atomic-scale control that nanotechnology yields.

Drexler's vision caused excitement by opening up a vista of assembling any kind of molecule atom by atom, as long as the final molecule was energetically stable. The tremendous difference between pushing the chemically inert xenon atoms around on a surface and the assembly of large 3D molecules was elided, and appropriately so when the aim is to inspire and enthuse. And Drexler's vision gained in force by his comparison with the DNA-RNA-protein complex. He argued that nanotechnology could assemble molecules resembling the building blocks of life in that these new molecules themselves produce new molecules. In other words, we would design new life-like systems in real life, just as artificial life was being generated on computers (Drexler 1987).

iNANO

Organization

The broad guidelines for iNANO's efforts are decided upon in the iNANO board, which consists of representatives from industry and the two universities:

- Research Director Ove Poulsen, NKT Research A/S (chairman)
- Research Director Hans Jørgen Pedersen, Danfoss A/S
- Research Director Bjerne Clausen, Haldor Topsøe A/S
- Research Director Klaus Bock, Carlsberglaboratoriet
- Director Ole Jensen, NanoNord A/S
- Dean Erik Meineche Schmidt, Faculty of Science, University of Aarhus
- Dean Søren Mogensen, Faculty of Health Sciences, University of Aarhus
- Dean Finn Kjærsdam, Faculty of Science, Aalborg University

The center is directed by Prof., DrSc Flemming Besenbacher (Aarhus). Prof. Niels Chr. Nielsen (Molecular Biology, Aarhus) and Associate Prof. Kjeld Pedersen (Physics, Aalborg) act as Deputy Directors. All were appointed by the board.

Industrial partners

Several national and international companies have entered into a formalized collaboration with iNANO through their support of research and/or educational activities:

- NKT Research A/S www.nkt.dk
- Danfoss A/S www.danfoss.dk
- Haldor Topsøe A/S www.topsoe.dk
- Carlsberglaboratoriet www.crc.dk
- NanoNord A/S www.nanonord.dk
- H. Lundbeck A/S www.lundbeck.com
- Grundfos A/S www.grundfos.com
- Exiqon A/S www.exiqon.dk
- Novozymes A/S www.novozymes.com
- Sagres Discovery (USA) www.sagresdiscovery.com

Further information

Detailed information on iNANO can be found on www.inano.dk or by contacting the center management:

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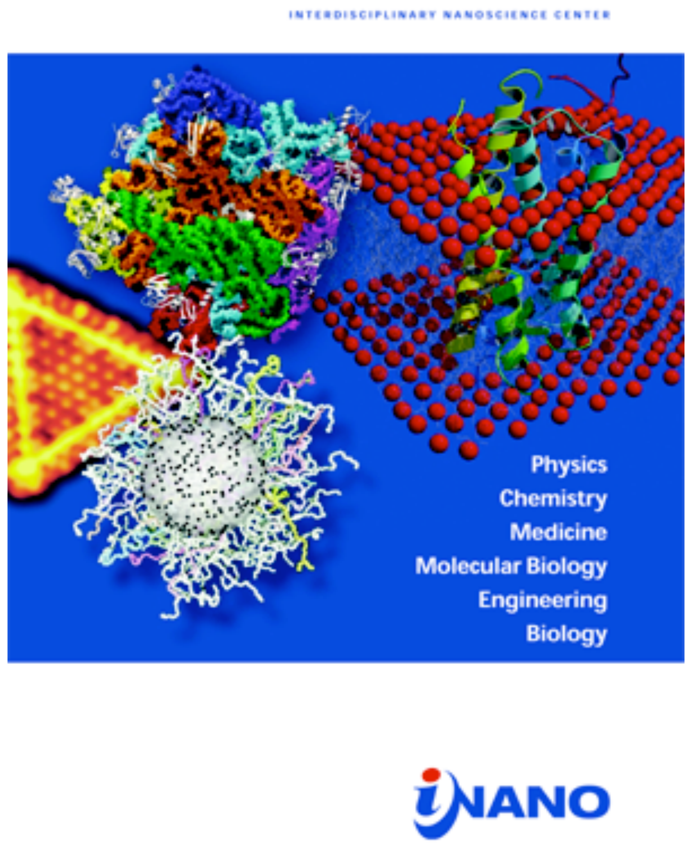

Figure 2: iNANO's 5 molecules

The same three molecules also grace pages 2 and 3 of a pamphlet introducing the center—and displayed on iNANO's website (Figure 2).[4] In large white letters the disciplines involved in the center are stated: physics, chemistry, medicine, molecular biology, engineering, and biology. In small letters on the left is a list of senior researchers and industrial partners.

The largest and most visible molecule is the bacteriorhodopsin which has also been incorporated into the banner of iNANO's website. Visually, it consists of two planes of red balls, connected by curled strands. The planes look more like the topic of surface science, whereas the curled strands show us that we are in the realm of biology. It is thus both appealing and eloquent about interdisciplinarity. To the left of it is the ribosome (below which is a molecule of less concern for the purposes of this paper), and further to the left the molybdenum disulfide molecule that the CAMP group had analyzed using an STM with a view to improvements in catalysis. These four molecules fill the right half of the image. On the left half and somewhat isolated from the other four we find a DNA strand. The intended audience for this pamphlet is wider than scientific colleagues. It is well suited for visitors to the lab, including high school students, or for distribution amongst journalists, administrators, and politicians. It is the kind of glossy genre that assumes a distracted reader. The coloring is striking, with a blue background and each of the five molecules consisting of a major color: red, green (and brown), white, orange, and purple; the prose is crisp and to the point, introducing the theme of nano, summarizing the funding structure and mission of the iNANO center along with its research and teaching activities.

The Sublime

The image fronting the US National Nanotechnology Initiative report issued in 1999, by comparison, is much more direct in its hype. It was also intended for a non-specific audience, also aiming to advertise nano, and also with a view to supporting funding for research. Here, we have an STM-produced image of a surface but set, not against a plain blue background but the starry sky with Earth, Moon, and a falling star. The report itself explains that: "The combination of a scanning tunneling microscope image of a silicon crystal's atomic surfacescape with cosmic imagery evokes the vastness of nanoscience's potential." Alfred Nordmann has made a number of interesting suggestions about this image that may aid also in the understanding of the Danish image (Nordmann 2004). First of all, the US image juxtaposes a macrocosm and microcosm, of outer space and inner space, suggesting a continuation of the frontier dream: going where no man has gone before. Secondly, the "mystical or forbidding presence of artefacts...floating through space, appear[s] to defy their origin in human social practice" (2004). Nordmann suggests that it inadvertently anticipates Bill Joy's worry that the nanotechnological future may not need us. While distracting attention away from the social nature of nanoscience, it focuses our attention on to our machine-enhanced sensory modalities: the perception of the very small and the very large; a point made almost ubiquitously in popularizing literature on nanoscience with a scale of images at powers of 10, for example at meters, millimeters, micrometers, and nanometers.

In the Danish image there are no vistas of outer space and inner space. The references to the vastness of nanotechnology's potential are more subtle because the original legends are now left out, but readers of the newspaper article will recognize the symbolic meaning intended for the molecules. And the molecules are certainly presented as divorced from human or social practice.

The DNA molecule in figure 2 is slightly off to one side, presumably because unlike the other four, it is not a molecule that the iNANO researchers have worked on. But its inclusion resonates with the promise of nanotechnology to design new molecular systems that are just as powerful as DNA and RNA—in fact the DNA molecule might be thought to be emphasized through its placement on page 2, one page before the other four. In the days of a shrinking physics budget and a growing life sciences budget, the one icon one wants to associate oneself with is the double helix of DNA (Nelkin & Lindee 1995).

And so while iNANO's visual language is subdued (just as Danish Lutheran churches are visually very restrained), it still encodes exhilaration. The phrases Besenbacher uses when addressing newspaper readers (Besenbacher 2002) and high school students[5] show us where the decoding is meant to take us: enormous potential, as yet unknown possibilities, fantastic possibilities, and the next industrial revolution.

One may pursue the question whether the promise or hype is justified, and whether the reader is being duped by the assertions (limiting oneself to the truth discourse). But this may be an inappropriate yardstick for the science hype genre. Instead, one might ponder the importance of a genre that invites revelry in an imagined future. Such revelries have a value all of their own. To get at this issue, I will take a short detour through audience studies that have developed alternative yardsticks in opposition to the "dominant" discourse of truth and falsity. Nick Stevenson has summarized John Fiske's argument:

> What is important about the tabloid press is not whether the articles and features it runs are actually true, but its oppositional stance to official regimes of truth. Fiske illustrates this argument by referring to a story concerning aliens landing from outer space, which he claims to be a recurrent one within tabloid journalism. The point about such stories is that they subversively blur the distinction between facts and fiction, thereby disrupting the dominant language game disseminated by the power bloc. Further, while official news attempts to ideologically mask the contradictions evident within its discourse, the tabloid press deliberately seeks to exaggerate certain norms, hereby *abnormalising* them. Fiske's argument here is that the sensationalised stories characteristic of the tabloid press produce a writerly text in that they openly invite the interpretive participation of their readers. The tabloids, like other popular texts such as Madonna and soap operas, maintain their popularity by informing the people about the world in a way that is open to the tactics of the weak (Stevenson 2002, 94).

The prophetic prose and visual language of nanohype may resemble tabloid journalism in this sense (not in the sense of being true or false). Whereas technical texts tell readers what is the case, leaving little room for interpretation, especially without substantial technical training, the playful suggestions of nanohype enable the reader to imagine and to enjoy imagining. Thus Besenbacher, in addressing high school students and the general public, wisely refrains from technical detail and instead invites revelries that for many readers will be pleasurable. The readers are expected to be distracted, maybe thumbing through the pamphlet during a spare moment, or reading the newspaper during breakfast. The reader is not expected to commit any facts to memory (connoting tedium) but rather to daydream.

As Colin Milburn has convincingly shown, science fiction is in the background of much nanoresearch. The Drexlerian vision has clearly taken elements from science fiction, as did Richard Feynman who gave a lecture entitled "There is Plenty of Room at the Bottom" in 1959, a lecture which is now often (paradoxically) referred to with a view to establishing nanotechnology's scientific origins (Milburn 2002). And science fiction has this same characteristic: it invites playful revelries of the future; it prompts pleasure.

It has been suggested that a core element of science fiction is its delight in the sense of wonder, sometimes referred to as sensawunda or as the sublime. Science fiction editor David Hartwell has summarized it thus:

> A sense of wonder, awe at the vastness of space and time, is at the root of the excitement of science fiction. Any child who has looked up at the stars at night and thought about how far away they are, how there is no end or outer edge to this place, this universe—any child who has felt the thrill of fear and excitement at such thoughts stands a very good chance of becoming a science fiction reader.
>
> To say that science fiction is in essence a religious literature is an overstatement, but one that contains truth. SF is a uniquely modern incarnation of an ancient tradition: the tale of wonder. Tales of miracles, tales of great powers and consequences beyond the experience of people in your neighborhood, tales of the gods who inhabit other worlds and sometimes descend to visit ours, tales of humans traveling to the abode of the gods, tales of the uncanny: all exist now as science fiction.
>
> Science fiction's appeal lies in its combination of the rational, the believable, with the miraculous. It is an appeal to the sense of wonder (Quoted in James 1994, 105).

It is this sense of wonder that resonates in Besenbacher's use of words such as "dizzying," "unbelievably small," "undreamt-of," "fantastic," "visions," "unimaginable," "as yet undefined," and "ground-breaking" (Lindberg 2001; Besenbacher 2002).[6] And the images encode some of the same sense of wonder. As an aside, it would seem that science fiction is turning away from the original general trope of exploring empty space and alien worlds. Cyberpunk, one of the more recent genres of science fiction is more concerned with communication technologies, cyborgs, and technologically altered minds (*e.g.* Gibson [1984] & Goonan [1994]). The NNI is clued in to this development: its current mantra is

NBIC (nano-bio-info-cogno) convergence. The mantra certainly refers to interdisciplinarity, but also to the sense of hype in the latest science fiction literature. This is an aside because I haven't found an instance of the Besenbacher group referring to NBIC.

But the pleasurable reading of possible futures is being constantly challenged by the discourse of truth and falsity. Just as science fiction as a genre has historically been marginalized and science fiction fandom ridiculed, so the nanovisions are under attack. Largely, this is prompted by the desire to have transparency in a political process that earmarks millions of dollars in pursuit of a vague future. But it is driven even more by the dual nature of new technology: the theme of the wizard's apprentice. Media reports on nano have picked up the Drexler vision, accelerating greatly with the publication of *Prey* by Michael Crichton, the author of Jurassic Park (Anderson *et al* 2004. Cf. also Stephens 2004). In *Prey*, we have nanorobots instead of dinosaurs, but the theme is the same: they escape and wreak havoc upon humanity. With this publication, the pleasurable revelries of the future are turning into nightmares, thus threatening to undermine the political will for nanotechnology funding. The response in the nano-community has been to emphasize differences between actual nanoresearch and the research featured in *Prey*. Drexler himself has expressed frustration that his vision is being tarred with the brush of *Prey* (Drexler 2004).

Faced with similar hostility to nano in Danish newspapers, Besenbacher also has emphasized the need to distinguish science from "mere science fiction" (Besenbacher, quoted in Holm 2004). The blurring of the boundary between truth and fiction is desirable when that blurring leads to exhilaration, but not if it leads to fear. Phrased thus, Besenbacher's stance appears inconsistent, but in strategic terms it is clearly not.

Movies

I will now turn to the webpages and to the STM movies. They were created during the CAMP project that ran from 1992 to 2002 and prominently displayed on the CAMP website. They are still present on the iNANO website but not with top billing. Thus, in a snese, we are moving to the left in Bucchi's diagram.

Erik Lægsgaard, the designer and builder of the Aarhus STM, thinks explicitly in terms of adapting scientific instrumentation to the human senses. For example, we humans are very good at noticing a duck waddling across a lawn. We sense immediately that the background is staying fairly stable and the real change in front of us is the movement of the duck. Trees may sway, and waves in a pond may constitute movement too, but we recognize with ease that these movements always return to the original position and so we can block them out of our attention. Similarly, we can recognize diffusing single atoms against a fairly stable surface. Scientific instrumentation and computer programs have a much harder time with such recognition. Hence, Lægsgaard argues, it makes sense to make movies and use the human senses for just this kind of research. Similarly, during the development of the STM in the 1980s, Lægsgaard, a passionate radio amateur, decided to use sound in the tuning of the STM. Lægsgaard argues that it is much harder to generate a visual image of similar utility, and that the human ear is especially well suited to recognizing the kind of sound that signals a properly functioning instrument.

These movies were used in research and so the first audience was the CAMP/iNANO researchers themselves, trying to get a grip on the nanoworld. They were displayed at conferences as well, making the scientific colleagues the second audience. The websites configure a third, larger, audience. I will address pleasure in the larger audience first and get back to pleasure amongst scientific colleagues. A member of the lab, Anne-Louise Stranne has presented just such a movie with the help of 6 stills in a glossy science-popularizing journal. The article is structured to make the point that:

> nanotechnology is based on complete control of atoms' behavior. With complete control, a whole new world will open up providing opportunities for constructing and using materials. Individual atoms may be used as small machines moving other atoms, and it will be possible to generate electrical components from a small set of atoms. And that's just the beginning.

But to reach this promised land of technology, one must be sure that the atoms don't move or react in an uncontrolled fashion. It is here that research of atoms on surfaces enters the picture (Stranne 1999).

The movies are placed most prominently on the CAMP website, just under the banner. (They are also accessible from the iNANO website, as is Stranne's article). The movies are in yellow-orange-red, brown colors and consist of points moving along a background pattern that remains comparatively stable. We are informed in the legend and surrounding text that these are atoms diffusing along surfaces. Each still of the movie is an STM scan of the surface, and we are actually watching 30 minutes of action compressed into a few seconds, so that the motion of the diffusing atoms becomes easily recognizable. The newspaper article mentioned repeatedly above (in *Jyllandsposten*) is placed on that website and with a feedback link to its author (Flemming Besenbacher) along with one to the movies.[7]

What may the intention of placing movies on the website be? For one thing, they allow something like a voyeuristic sense of control of the nanoscale: Take a peep at the hitherto unseen world! A world that humanity has wanted to access for centuries—a world thematized in the mid-20th century by George Gamow's *Mr. Tompkins* and other sf authors, and more recently on US National Public Television by *The Magic School Bus*. And comprehension is easy: any viewer can discern the atom moving across the surface—quite unlike most visual scientific material. In other words, a part of the fascination with the movie consists of visual access to atomic scale: from being able to see individual atoms move to controlling such atoms seems but a small step! As in Eigler's experiment with xenon atoms, it evokes control of the nanoworld and the pleasurable revelry of revolutionary future technologies. The pleasurable revelry is available with one click—it may reach a distracted audience such as high school students searching for something cool.

It deserves mention also that these movies were up already in 2000 when the appearance of the internet was still largely static. I remember watching these movies then, being fascinated simply because they were on my computer screen, not on the TV. With time, the pleasure of watching just any movie on the web has obviously waned.

The Intraspecialistic Stage

I will now turn to pleasure among scientists, by examining an article in *Physical Review Letters* analyzing a movie. This audience is not presumed to be distracted, quite the opposite. Hence visuals are in plain black and white, and the mode of discourse around them is matter-of-fact without any overt references to futuristic revelries. Instead, the arguments attempt to leave as little as possible for the audience's imagination to play with. In fact, readers of scientific publications may be presumed to be on the prowl: looking for resources that they can use in their own research. Attendees at scientific conferences may also be looking to score points with the audience by asking penetrating questions. In either case, the audience is highly focused and critical of any ambiguity.

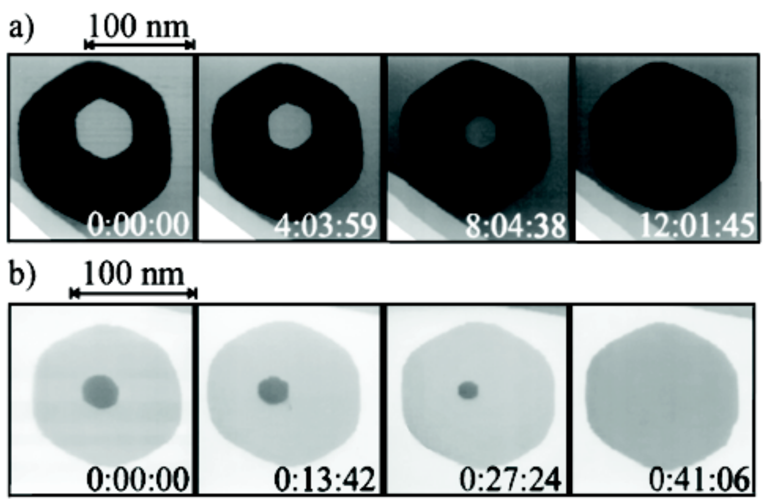

Figure 3: Four stills from a movie

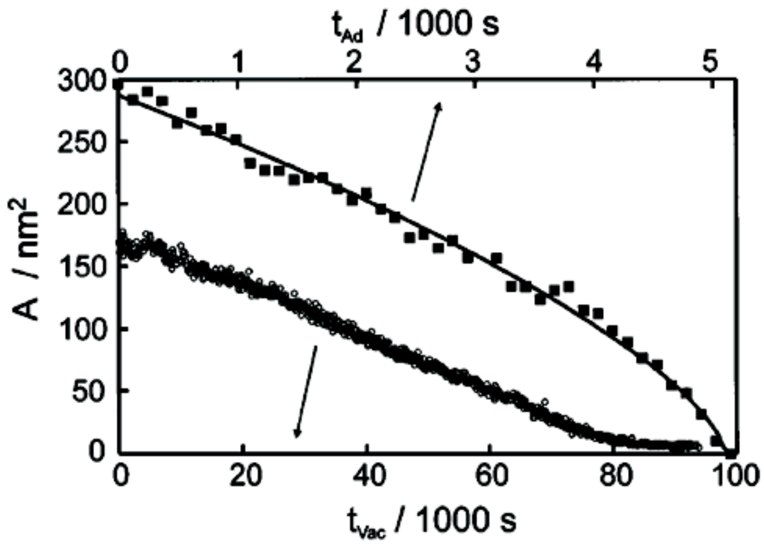

Figure 4: Graph of decay

The graphs (Figure 4) are derived from the movies (Figure 3). One movie is of hexagonal assemblies of atoms upon the surface of a silver crystal.[8] The movie shows the gradual decay of these nanostructures, as the authors call them. The publication using this movie treats the movie as a means to an end (Morgenstern *et al* 1998). The display of a set of four stills gives the reader a general sense of the appearance of the movie and highlights the decay. This information is transformed into a more succinct, graphical representation of the decay. For each still of the movie (many more than the four used earlier on in their publication) the area of the nanostructure is measured. The measurements are displayed on a graph, the axes being area and time. The resulting graph contains a continuous curve falling off to zero, symbolizing the degradation of the structure. (The same experiment is done with "vacancy island decay", a flat hole on the surface which is then gradually filled up; hence the graph has two lines.) The point that the authors want to get to is the kinetics that causes these decays, and here they engage with the so-called Ostwald ripening model. They discuss what the measurements tell us about the model, that is to say to what extent the measurements support the model and to what extent the model assures the experimenters that their results are sensible, as opposed to, say, an artifact of the STM.

In other words, the movies need to be summarized into a conspectual view, most often a graph, from which even more succinct information (numbers) about the decay may be formed, such as the linearity of the decay and the gradient of the line. These numbers can then be fed into a quantitative model and the implications for the trustworthiness of each discussed. Of course, much scientific work is of this kind: a cascade of representations, summarizing information to ever-higher degrees of abstraction, the highest level of which is theory—or models (Latour 1987).

As mentioned, the audience is configured as attentive and interested. There is no color and little fireworks. The reader is expected to understand the jargon of surface physics and know how to read graphs. The Ostwald ripening theory is explained in some detail, but to follow the argument the reader must know, say, differential equations and Arrhenius plots. Some level of scientific literacy is required. The majority of the population will have no interest in this paper and would not be able to make any sense of it.

Even here the initiated may experience pleasure. There may be pleasure in deciphering highly abstract codes, in communicating at a very abstract level, and in figuring out the consequences for one's own research. And there may be pleasure in belonging to a select group of individuals that is thus enabled—especially if this group can see itself as superior in some way, such as more rational than the rest of the population. In other words, just as maps are capable of solidifying national identities, so graphs may be capable of solidifying disciplinary identities.

And there may be at least two further sources of pleasure in this publication. The authors frame the importance of the paper thus:

> The control of kinetic parameters in thin metal film growth is of utmost importance for the ability to design novel nanoscale structures.

> As many nanoscale surface structures are only metastable, it is important to know on what time scale material rearranges and whether these processes can be used for modifying nanostructures on surfaces.

This is indeed the nanohype theme so prominent in the popularizing literature. The Drexler dream requires control at the nanoscale, and this paper will inform you of an aspect of just that.

The second additional source of pleasure lies in the power of the STM to produce images and movies. As I have argued elsewhere (Hessenbruch 2004), the early source of surface scientists' fascination with the STM was three-fold: atomic resolution, and the imaging in real-space, and real-time. Getting images of individual atoms had been something of a holy grail in science throughout the 20th century—overlaid with the mystique of the uncertainty principle. Most people, including many scientists, understood the uncertainty principle to rule out the possibility of the imaging of individual atoms. Hence scientists also felt the pleasure of voyeurism, when seeing the first STM images. Until the 1980s, scientists had their information from such techniques as x-ray diffraction, which is powerful but sums over many atoms at a time. The information about, say, the structure of DNA was encoded in a space that differed from real space, and one space could be mapped on to the other with Fourier transforms—a mathematical technique.[9] Generations of crystallographers learnt to think in Fourier space, and the intriguing nature of STM images was that they provided images directly in real space—no need for a Fourier transform. Finally, x-ray images require the summing over longer periods of time. One cannot do snapshots of crystals using x-rays and then see how the crystal changes over time. STM movies are precisely this: they show you developments in real time. All these three factors must have rendered STM movies "cool" to scientists, adding pleasure to the publication under discussion.

Conclusion

Pleasure may thus be found in all of Bucchi's stages and it should be clear that the question of truth and consensus cannot encompass all the goings-on in the public sphere. Also, the existence of esoteric texts, textbooks, popularizations and TV shows made us think of a fragmented discourse so that certain texts and images address certain audiences only, depending on their level of expertise. By contrast, I have shown that the audiences addressed are heterogeneous.

The textual and visual language is writerly, in Barthes' sense. This is quite obvious in the newspaper articles, but writerly language may even be detected in the *Physical Review Letters*. Just as Benedict Anderson has argued that maps have "penetrated deep into the popular imagination" (Anderson 1983) and contributed to the making of national identities, so a similar group identity may be enhanced by images of molecules as machines, and images of inner and outer space. Certainly, Besenbacher's PR-work is intended to tie together networks of support. Constant maintenance work is required lest parts of the network disengage, constant work is required to establish new contacts.

Latour's talk of heterogenous networks seems apposite here: Besenbacher enrolls actants (humans and adatoms). In 1987, Latour still talked of trials of strength: the stronger network would sustain a stronger claim on truth. But the networks discussed in this article primarily sustain funding, not truth. And indeed Latour's recent work (*e.g.* Latour 2004) has shifted towards the politics of sustaining heterogeneous networks in general—not just in order to win a struggle among versions of truth. As such, this paper is in accord with that aspect of Latour's trajectory.

Bucchi's diagram is static in time. It doesn't allow for changes in the public sphere, a change that Habermas has documented in the long term. The development from surface physics through CAMP to iNANO indicates further changes. But to what extent is the story described here representative? Besenbacher is an exception within the Physics Department of Aarhus University. Other professors there, such as Steensgaard, do not publish popularizing articles, sit on government committees, commission nicely designed websites, or devise and write new grant proposals. They write scientific papers and communicate with their peers. These professors still live science as they did 30 years ago. However, the next generation is being trained to behave like Besenbacher. In other institutions, such as MIT or Stanford, and in other departments, such as the life and medical sciences, the practice of interdisciplinary, networking science with a view simultaneously to the market and to 'pure science' is much more common. Gibbons *et al* have argued that science has been gradually shifting in this sense for a few decades, and this paper adds to the evidence (Gibbons *et al* 1994).

The same group of authors has more recently pointed to current science's similarity with derivatives in financial markets, such as "futures." Here "economic activity derived from first-order operations rooted in material production and exchange is displaced onto a second-order level where abstraction and speculation predominate…Innovation has acquired an urgent, even quasi-moral, stridency" (Nowotny *et al* 2001, 67). "Collusions of interest…tread a thin line between authentic belief in the future potential and mere rhetoric of 'selling' a particular line of research to politicians and the public. Promises come first…in order to instill and stimulate demand which later will underpin a market" (Nowotny *et al* 2001, 37-8). Potentiality tends to take precedence over actuality. This fits nano to a tee. Nano is full of promises based upon a potential, the assessment of which is difficult, but which are elaborated upon and amplified in the media. These promises excite the imagination of industry, the public, and members of parliament, and influence research funding decisions. They also help establish new disciplinary boundaries (Guice 1999; Hedgecoe 2003). That such a centripetal force is indeed taking place under the banner of nano has been clearly demonstrated by Schummer 2004).

Now, the effect of expectations is not new. A part of Colin Milburn's argument (Milburn 2002) is that science fiction played a role in Feynman's argument about "plenty of room at the bottom." But this doesn't mean that science fiction has always played the same role. With the changes in funding structures, more and more scientists are urged or encouraged to behave like Besenbacher. The role of science fiction and exhilaration is increasing.

The policing of hype needs to change accordingly. Why insist that fears instilled by science fiction (*Prey*) must be marginalized as fiction when at the same time hopes are classified as possible fact? This opens up the question of accountability of hype. Research is supposed to be more accountable now when commercialization has replaced filling in a gap of knowledge as the yardstick, but when research gambles on future markets accountability seems hard to achieve. Can we account for some of the value of nano in the pleasure of expectation it gives, regardless of whether the promise actually comes to fruition?

At any rate, Bucchi's diagram falls short for two reasons: it is simplistic in focusing only on truth and not on the circulation of money and the selling of dreams[10]; and it ignores historical changes in science and the public sphere. Fitting the role of pleasure into Bucchi's diagram will, however, pose severe problems. The important category is not expertise but the politics of funding. Besenbacher's newspaper articles address simultaneously several of Bucchi's stages, and a politician might read it with a view to voters' interests at the next election. An investor might read it thinking of where to put his or her high risk investments. The manager of an industrial company might read it thinking of investors wanting to invest in nanorelated research. Think tanks and government bodies deciding upon funding structures use a managerial cost-benefit language shorn of hype. Nonetheless, the very reason for funding nano is the uncertain promise that no private company is prepared to bet on. The whole discourse of fact-truth-knowledge-authority-expertise-objectivity-disinterestedness-credibility concerns itself with what is the case, neither with what might be the case nor with revelries of what might be influencing what is.

Should we therefore abandon attempts to map science in the public sphere? I think not. Bucchi's diagram has great heuristic value. It has to be more complex to fit the realities on the ground, and it needs to incorporate temporality. In fact, the very complexity of the resulting map will likely defy its original purpose: to provide a conspectual view. But there will be pleasure in the attempt.

References

Anderson, A., S. Allen & A. Petersen. 2004. "Pictorial and Textual Representations of Nanotechnology in the UK Press." paper given at University of South Carolina conference: *Imaging and Imagining Nanoscience & Engineering*, March 2004.

Anderson, B. 1983.*Imagined Communities: reflections on the origin and spread of nationalism*, London: Verso.

Barthes, R. 1975. *S/Z: an essay*. London: Jonathan Cape.

Besenbacher, F. 2002. "Kronik: Småt har aldrig været større." *Jyllandsposten-Århus* (9 June).

Bucchi, M. 1998. *Science and the Media – Alternative Routes in Scientific Communication*. London & New York: Routledge.

Collins, H. M. & T. Pinch. 1998. *Golem: What You Should Know About Science*. Cambridge: Cambridge University Press.

Daston, L. & P. Galison. 1992. "The Image of Objectivity." *Representations* 40: 81-128.

Drexler, E. 1987. *Engines of Creation*. Garden City, NY: Anchor Press/Doubleday.

Drexler, E. 2004. "Visions of Nanotechnology: A World Divided." paper given at University of South Carolina conference: *Imaging and Imagining Nanoscience & Engineering,* March 2004.

Fleck, L. 1979. *Genesis and Development of a Scientific Fact*. Chicago: The University of Chicago Press.

Gibbons, M., C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, M. Trow. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*, London & Thousand Oaks: Sage.

Gibson, W. 1984. *Neuromancer*. New York: Ace Books.

Goonan, K. A. 1994. *Queen City Jazz*. New York: Tor.

Grønbæk, D. 2001. *Mellem politik og videnskab – Reform af det danske forskningsrådssystem 1994-1997*, Institut for Statskundskab – Københavns Universitet, Copenhagen.

Guice, J. 1999. "Designing the Future: the Culture of New Trends in Science and Technology." *Research Policy* 28: 81-98.

Habermas, J. 1989. *The Structural Transformation of the Public Sphere: An Inquiry into a Category of Bourgeois Society*. Cambridge, MA: MIT Press.

Hedgecoe, A. M. 2003. "Terminology and the Construction of Scientific Disciplines: the Case of Pharmacogenomics." *Science, Technology, and Human Values* 28: 513-537.

Hessenbruch, A. 2004. "Nanotechnology and the Negotiation of Novelty." In J. Schummer & A. Nordmann (eds.), *Discovering the Nanoscale*. Amsterdam: IOS Press.

Hilgartner, S. 2000. *Science on Stage – Expert Advice as Public Drama*. Stanford: Stanford University Press.

Holm, S. 2004. "Forskere frygter nanoskræk." *Information* (2 February).

James, E. 1994. *Science Fiction in the 20th Century*. Oxford & New York: Oxford University Press.

Latour, B. 1987. *Science in Action*. Milton Keynes: Open University Press.

_____. 2004, *Politics of Nature: How to Bring the Sciences into Democracy*. Cambridge, MA: Harvard University Press.

Lindberg, K. 2001. "Den mindste af alle verdener", *Berlingske Tidende*, 8 March(and http://www.berlingske.dk/popup:print=90050?&)

Lundager Jensen, B. 1996. "Dansk forskningspolitik – fra finkultur til national strategi." *Samfundsøkonomen* 4: 28-39.

Milburn, C. 2002. "Nanotechnology in the Age of Post-Human Engineering: Science Fiction as Science." *Configurations* 10: 261-295.

Morgenstern, K., G. Rosenfeld, E. Lægsgaard, F. Besenbacher, & G. Comsa. 1998. "Measurement of Energies Controlling Ripening and Annealing on Metal Surfaces", *Physical Review Letters* vol. 80 (19 January): 556-559.

Morus, I. 1998. *Frankenstein's Children: Electricity, Exhibition, and Experiment in Early-Nineteenth-Century London*. Princeton: Princeton University Press.

Nelkin, D. & M. S. Lindee. 1995. *The DNA Mystique – The Gene as a Cultural Icon*. New York: W. H. Freeman and Company.

Nordmann, A. 2004. "Nanotechnology's WorldView: New Space for Old Cosmologies." paper given at University of South Carolina conference: *Imaging and Imagining Nanoscience & Engineering*, March 2004. This paper is available in German: http://www.cla.sc.edu/cpecs/nirt/papers/AN2.html

Nowotny, H., P. Scott, & M. Gibbons. 2001. *Re-thinking Science – Knowledge and the Public in an Age of Uncertainty*. Cambridge, England: Polity.

Porter, T.: 1995, *Trust in Numbers: The Pursuit Of Objectivity in Science and Public Life*. Princeton: Princeton University Press.

Schummer, J. 2004. "Multidisciplinarity, Interdisciplinarity, and Patterns of Research Collaboration in Nanoscience and Nanotechnology." *Scientometrics* 59: 425-465.

Shapin, S. 1990. "Science and the Public." in R. C. Olby et al, (eds.). *Companion to the History of Modern Science*. London: Routledge, 990-1007.

_____. 1994. *Social History of Truth: Science and Civility in Seventeenth-Century England*, Chicago: Chicago University Press.

Shapin, S. & S. Schaffer. 1985. *Leviathan and the Air-Pump*. Princeton: Princeton University Press.

Shinn, T. & R. Whitley. 1985. *Expository Science: Forms and Functions of Popularization*. Dordrecht: Kluwer.

Stevenson, N. 2002. *Understanding Media Cultures – Social Theory and Mass Communications*, 2nd edition. London, Thousand Oaks, New Delhi: Sage.

Stephens, L. F.: 2004, "News Narratives About Nano: How Journalists and The News Media are Framing Nanoscience and Nanotechnology Initiatives and Issues." paper given at University of South Carolina conference: *Imaging and Imagining Nanoscience & Engineering*, March; also http://129.252.169.87/rstephens/stephensnanomsUSCMar04.pdf.

Stranne, A.-L. 1999. "Nanoteknologi er vejen frem." *Aktuel Videnskab* 1: 11-14.

Endnotes

[1] Interviews with four members of this Danish group (Besenbacher, Steensgaard, Lægsgaard, and Vang Lauritsen) may be found on http://hrst.mit.edu. Hard copies of these interviews will be deposited in the Burndy Library.

[2] http://www.phys.au.dk/camp/pdf/science-uk-press-release.pdf

[3] http://www.forsk.dk/snf/publ/stratplan/strategi_03_07eng.pdf

[4] http://www.inano.dk/graphics/iNANO-system/File-links/inano_final.pdf

[5] http://www.destination-fremtiden.dk/nanoart.asp. The name of this website translates as "destination: the future"; using the English word for destination connotes something other than the mundane.

[6] Also iNANO pamphlet: http://www.inano.dk/graphics/iNANO-system/File-links/inano_final.pdf.

[7] The site is constantly being reorganized and since April 1, 2004, some of these links have disappeared—but the links to the movies have always remained intact.

[8] Adatoms on a Ag(111) surface.

[9] For brevity's sake the phase problem is ignored here.

[10] It ignores also activities such as political lobbying and the legal discourse of intellectual property or regulation; the relevance of all of which have been demonstrated at the *Imaging and Imagining* conference in Columbia, South Carolina, March 2004.

Analyzing the Complexity of Nanotechnology

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The Complexity of Technology

In the past decades engineers have increasingly been confronted with the complexity of technological developments. In the 1950s and 1960s engineers could afford to focus very much on the scientific and technical aspects when developing new products, because they knew that it would not be difficult to be successful on the market. Customers could afford to explore all sorts of new gadgets, as there were no real economic barriers for them. Also there was not yet an organized resistance against technology in society. Issues such as environmental damage and ethical questions were not really urgent at that time. This changed in the late 1960s and early 1970s, and from then on engineers have learnt that it is nowadays not enough to come up with a nice technical idea. A great variation of conditions needs to be met. Not only should the new product fit with the current scientific and technological insights, but also economic, social, legal, aesthetical, environmental, psychological and numerous other conditions need to be taken into account when developing new products. This makes the work of engineers both complex and challenging. It also brings about the need to reflect on the nature of this complexity. The question emerges if it is possible to analyze this complexity in a more or less systematic way.

This question most certainly applies to the field of nanotechnology. Although still in its infancy, it clearly is a field in which quite a variety of aspects have to be taken into account. Not only are there gaps in our scientific knowledge, for which reason some people rather talk about nanosciences and wonder if one can use the term nanotechnology at all, but also there are great uncertainties about what will be feasible in the future, and what will appear to be mere 'guru talk' in the end. Already now institutes in a number of countries have started ethical debates about nanotechnology. Also the question has been raised how to set up new legislation for this emerging field, even though it is still uncertain what that legislation should exactly cover. Others worry about economic aspects of nanotechnology and in particular industrial companies are confronted with the difficult question if, and if so, how to invest in this still uncertain new type of technology. In other words: already now it is clear that the development of nanoscience and nanotechnology is a matter of great complexity, in which many different factors and issues are involved. For that reason, here too there is a need to analyze this complexity, in order to gain insights that can support decision making with respect to developments in nanoscience and nanotechnology.[1]

Analyzing Technological Complexity

Several options for analyzing the complexity of technological developments have been suggested. Perhaps the most basic one is the "Dual Nature of Technical Artifacts" approach, which is investigated at the Delft University of Technology.[2] In this approach, a technical artifact is analyzed according to the two natures it has: a physical nature and a functional nature. The physical nature comprises the non-relational (or non-intentional) aspects of the artifact, such as its size, shape, weight, structure, and so on. The knowledge about this nature of the artifact is, generally speaking, of a descriptive nature. On the other hand there is the functional nature of the artifact, which refers to what the artifact should enable us to accomplish. This nature involves relational (intentional) aspects, and the knowledge about this nature has a normative dimension. When an engineer says: "I know that this is a screwdriver", (s)he means to say: "I know that this is a device that *ought to* enable me to drive screws". The "ought to" nature of this knowledge shows its normative nature. What the engineer has to do is to find a physical nature for the artifact-in-design that fits the desired functional nature." One could say: the dual nature approach analyses in terms of a two-fold complexity. One could wonder if two natures only are sufficient to justify the term 'complexity' here. On the other hand, in practice finding the fit between these two natures can already be quite a challenge for engineers.

In a response to the Dual Nature approach, Carl Mitcham (2002) pointed out that analyzing the artifact in terms of just two natures may be too much of a reduction. Therefore other, more detailed analyses may be necessary. Such an alternative analysis was developed by Andries Sarlemijn at the Eindhoven University of Technology. The acronym he came up with for his approach was STeMPJE, which stands for a range of factors that need to be taken into account in technological developments, if ever they are to be successful: scientific, technological, market, political, juridical and (a)esthetical factors. By applying this analysis to different examples of technological developments, Sarlemijn (1993) was able to show the need for distinguishing between different types of technologies. His distinction was based on differences in the dynamics of these factors in the course of a technological development. Comparing his approach with the Dual Nature approach, one could say that his M, P, J and E factors are a further explications of the functional nature of an artifact, while the S factors and partially the Te factors relate to the physical nature of the artifact (Te factors partially, because those factors also can deal with functional aspects of the artifact, and thus relate to the functional nature of the artifact). One might say that Sarlemijn's approach splits up the two-fold nature of a technical artifact into a six-fold nature. His taxonomy of types of technologies indicates that it makes sense to apply this more detailed analysis.

In this article a third, even further detailed approach will be described. This approach was developed as early as in the 1930s by a Dutch Calvinist philosopher, named Herman Dooyeweerd (1969). Because his approach[3] was only applied to technology by Hendrik van Riessen, who hardly ever published in English, it has remained fairly unknown internationally throughout the years. Yet, it has some features that make it interesting as an analytical tool to investigate the complexity of technological developments. By applying this approach to nanotechnology, I will argue that it offers an analytical instrument for reflecting on the complexity of technological developments, while at the same time it offers analytical tools for creating order in the possible chaos that emerges when one explores this complexity. Dooyweerd himself saw his approach as a direct consequence of his Christian perspective on reality. It is interesting to note, however, that recently philosophers coming from different backgrounds have discovered the possibility to use some of his concepts separate from this Christian perspective. In particular in the field of systems methodology, the Dooyeweerd approach is now used to gain insights into the complexity of systems and the design of systems. Bergvall-Kåreborn (2000), for instance, has combined some of Dooyeweerd's concepts with the Soft Systems Methodology, which had been developed by Checkland (1981) and others. In the Proceedings of the annual conferences organized by the Centre for Philosophy of Technology and Systems (CPTS), other examples can be found. These examples show how the analytical instruments that Dooyeweerd developed can have a wider implication than only for a specific denomination of philosophers.

Aspect	Application to objects
1. Numerical	Object have a certain number of parts
2. Spatial	Objects occupy a certain space
3. Kinematical	Objects can move or be moved
4. Physical	Objects can interact by mechanical cause-effect relations
5. Biotic	Some objects live or are a part of other living beings' environment
6. Psychic/sensitive	People can observe objects
7. Logical/analytical	People can reason about objects
8. Cultural/developmental	People develop objects
9. Symbolic/linguistic	People represent objects by names or other symbolic representations
10. Social	People can share objects
11. Economic	People can sell objects
12. Aesthetic	People can appreciate objects for their beauty
13. Juridical	People can make laws in which objects feature
14. Ethical	People can assess objects from an ethical point of view
15. Pistic	People can believe in the positive effects of objects

Table 1. Aspects of reality according to Dooyeweerd

Before applying Dooyeweerd's concepts to the field of nanotechnology, it is useful first to give a more general description of those concepts. Basically what Dooyeweerd claims is that reality can be analyzed in terms of fifteen aspects or modes of existence (see his New Critique, Vol. II). Those aspects can be seen in Table 1. Any entity exists in all of these modes: it has a numerical existence, a spatial, a kinematical, etcetera. Furthermore, Dooyeweerd's claim is that these aspects or modes of existence show a certain order: each 'higher' aspect presupposes the existence of the 'lower' aspects. For example: the spatial aspect cannot exist without the numerical (because we have one, two, three, etcetera dimensions). Similarly, the biotic aspect cannot exist with all previous ones (life presupposes the possibility of energy conversion and movement, and movement can not exist without space). Up until the psychic aspect, Dooyeweerd explicitly argued for this particular hierarchy in the aspects, but for the later aspects he wrote more loosely about their order, and it is obvious that here it is much more problematic to set up a proper argumentation for this particular order of aspects. For that reason, his followers have had many debates about the proper order of the aspects, and nowadays several of them take a fairly pragmatic approach and leave the exact order of the higher aspects in the middle. This approach will be used in this article. The number of aspects also has often been debated. Dirk Vollenhove,[4] one of Dooyeweerd's colleagues, for instance, challenged the idea that the historical (or development) aspect should be regarded as a separate aspect. In his opinion the concept of time, which overarches all aspects, should be seen as the proper conceptualization of development. In this article I will keep the historical aspect but take it as an expression of the fact that every entity exists in a developmental way: it is able to bring forth or has been brought forth itself. One could use the term 'cultural' or 'developmental' aspect for this.

Another important feature of Dooyeweerd's approach is that entities can have subject and object functions in the various aspects (i.e. can exist as subject or as object in the various modes or aspects). For instance, a stone can exist as a subject in the kinematical aspect: it can move. It can also exist as an object in the same aspect: it can be moved. In the economic aspect, it can exist as an object (it can be bought), but not as a subject (it can not buy). Likewise, all entities have a 'highest' aspect in which they can still exist as a subject. Here his idea of a hierarchy in the aspects is used by Dooyeweerd and at first sight it may seem that the uncertainties about the order of the aspects may weaken this subject and object function concept; but it does not really, because there is a discontinuity in the transition from the psychic to the analytic aspect. Humans are the only entities that can function as subjects in the aspects from the analytic aspect and higher on. For that reason the exact order of the higher aspects does not matter for the analysis of subject and object functions. A third concept related to functions is the qualifying function. This function indicates what defines the entity's purpose or reason for existence. The qualifying function of a coin, for instance, is in the economic aspect, where it functions as an object. The functioning of entities in the various aspects is further analyzed by Dooyeweerd in terms of the 'laws' that hold for the various aspects. To continue the example of the coin: for its proper functioning we need to take into account a 'law' that holds in the economic aspect, which says that each coin can only be spent one at a time. That is why we have to calculate how much money we need to buy something before we commit ourselves to the transaction. One could see this as a sort of 'law of conservation' and similar conservation laws are found in other aspects (for example in the physical aspect where we find the law of conservation of energy). Dooyeweerd distinguished descriptive laws (such as natural laws) and prescriptive laws (of which examples can be found in the technological domain: technical norms and standards, good practice, etcetera). The different aspects have different laws, although the example of the conservation laws show that there may be analogies between the laws in the various aspects.

How does all that apply to technology? Technical artifacts can be analyzed in terms of their functioning in the various aspects. We can get to know their character by investigating which aspect they can serve as a subject or as an object, and which aspect we must seek their qualifying function. By reflecting on the possible laws in each of the aspects that should be taken into account when developing the artifact, engineers can develop a list of requirements for the artifact design. By taking into account the full list of aspects, one can get a fairly detailed impression of the complexity of the design problem. The Dooyeweerd approach can be seen as an extension of the Dual Nature approach. There is a split between the biotic and the psychic aspect. Functioning as a subject in the lower aspects does not require intentionality (a stone can move without having an intentional state of mind), while functioning as a subject in the higher aspects does require intentionality (one can not buy or sell without having an intentional state of mind). For this reason one can say that the lower aspects relate to the physical nature of a technical artifact, while the higher aspects relate to the functional nature of the artifact. In a similar way one can see Dooyeweerd's approach as a further explication of Sarlemijn's STeMPJE approach (in fact, some of Sarlemijn's factors have the same name as some of Dooyeweerd's aspects).

The Complexity of Nanotechnology

Non-intentional Aspects

Having seen the basic elements in Dooyeweerd's analysis we are now ready to explore how this approach can be instrumental in analyzing the complexity of nanaoscience and nanotechnology developments. I will confine myself here to indicate what issues are raised by the application of Dooyeweerd's approach to nanoscience and nanotechnology without discussing those issues in further detail. Let us now examine what each of the aspects means for the case of nanoscience and nanotechnology.[5] I will take nanotechnology to be the manipulation of individual atoms and molecules at the nanoscale, and nanoscience to be the development of scientific knowledge of the natural phenomena on nanoscale, in so far as they are relevant to nanotechnology.

(1) Dooyeweerd's first aspect (see Table 1) is the numerical. It belongs to their existence that nanoartifacts can be numbered. Already in this first and seemingly unproblematic aspect we start seeing the complexity of nanotechnological developments. As we are within the realm of quantum theory, numbering particles is not as we are used to in the macroscopic world. Furthermore, the most far-reaching claim of nanotechnology, as stated by some nanotechnology visionaries, such as Eric Drexler (1986), is the totally bottom-up construction of macroscale artifacts. For manipulating individual atoms extremely large numbers of assemblers will be necessary in order to get macroscopic results within a reasonable time scale. Drexler has suggested a scheme that would solve this problem by claiming that this can be done in the same way as nature does it: replicators continuously produce the assemblers that make the desired artifacts, and their self-reproduction will speed up this process. But there is a problem here when copying this procedure from nature. Drexler's replicators and assemblers need to be universal in order to be able to produce any desired artifacts, while their biological analogs, enzymes and ribosomes, are always specific (Burkhead 1999). So it may well be that the problem in the numerical aspect of the nanoartifacts cannot easily be solved (if at all this would be an easy solution, for it is yet unclear what the technological analog of the natural solution would look like).

(2) Next we have the aspect of space. This aspect seems to be what defines nanotechnology, given the fact that nanotechnology by definition has to do with manipulating matter at the level of nanometers. Indeed, most of the struggles that nanoscience and nanotechnology go through are related to the fact that it is difficult to observe and manipulate things at this level.

(3) (4) The next two aspects in Dooyeweerd's approach are the kinematical and the physical aspects. I will take them together here, as some of Dooyeweerd's followers have suggested. Motion and energy aspects of nanoartifacts both need to be described in terms of quantum phenomena. This description is, as yet, in development, and this is why nanoscience and nanotechnology are so closely related and often mentioned together. The fact that the phenomena at nanolevel are not yet fully known, while at the same time scientists try to build nanoartifacts, has as an interesting consequence that the functional and the physical nature of nanoartifacts (the two natures in the 'Dual Nature of Technical Artifacts' approach; see above) are not entirely known, while usually at least one of them is fairly well known in the beginning of the design process. Here the creation of a physical nature and the ascription of functions to the resulting artifact almost happen at the same time. Philosophically, this is perhaps one of the most significant issues in nanotechnology. In particular the process of defining a qualifying function (in Dooyeweerd's terms, i.e. not only telling what the emerging artifact can be used for, but also what it's most important function will be) to the artifact is a process that may well be different in the case of the creation of nanoartifacts compared to more traditional design processes.

(5) The fifth aspect is the biotic aspect. Here too, problems have already been identified. Nanoartifacts will interact with living creatures, and this may create problems that are similar to the asbestos problems that have caused quite some concern in the past. So far for the non-intentional aspects.

Intentional Aspects

(6) Now for the intentional aspects, starting from the psychic. This aspect has to do with consciousness. Here a concern for nanotechnological developments is the fact that our awareness of nanoartifacts is very indirect. We can only conceptualize them through pictures that have been produced by using

complicated processes that are far removed from direct observation. A commonly used way of picturing nanoartifacts is by using spheres to indicate individual atoms. This image, of course, is more symbolic than realistic, because of the quantum characteristics of atoms. A different way of picturing nanoartifacts is used when the outcomes of scanning tunneling microscopy are displayed. In such cases we see a surface with blobs emerging from it. The story that we are told is, that the raised blobs represent atoms. But this again is no more than a pictorial tool to help us conceptualize for ourselves what a nanoartifact looks like.

(7) A problem that is more interesting from a philosophical perspective, but may also have practical impact on the development of nanoartifacts can be identified when we consider the next of Dooyeweerd's aspects, which is the analytic or logic aspect. Analysis to Dooyeweerd is related to distinguishing. One of the perhaps most intriguing problems of nanotechnology is the question of how it could blur the boundaries between living and non-living matter. In terms of Dooyeweerd's concepts, the issue can be formulated as follows: is it still possible to identify a transition between the nanoartifact having its 'highest' subject function (i.e. the highest aspect in which it can function as a subject) in the physical or in the biotic sphere, and if yes, how? If indeed nanoartifacts can be built atom by atom, and this could also result in living tissue, then how do phenomena that indicate life emerge in this process? Self-reproduction, for instance, can be seen as a phenomenon that is typical for life. When such a phenomena would emerge in a process of building nanoartifacts, this may mean that we have to take that into account when taking safety precautions. From biology we know that self-reproduction can have as a consequence that the life system becomes autonomous in its growth, which may result in a threat for other life systems. A similar aspect can be asked with respect to the transition from the biotic to the psychic aspect. Is it possible that characteristics of consciousness would 'suddenly' start to appear in the process of building a (very complex) nanoartifact, and if yes, would consequences could that have for our attitude towards that nanoartifact.

(8) Now we come to the historic or development aspect. This is the aspect that we study when we consider the way in which the field of nanotechnology develops. As we noted before an interesting issue in this respect is the

development taking place based on only partial knowledge of the underlying natural phenomena.

(9) The study of these phenomena is what the next aspect, the linguistic or symbolic aspect, refers to. It seems that here we have an example in which the 'technology as applied science' paradigm fails to account for the relationship between science and technology. The relationship between nanoscience and nanotechnology is much more complicated.

(10) The issues that can be identified by considering the next five aspects are all related to the fact that nanoscience and nanotechnology are, as yet, in a state of infancy and much is unknown about the possible social effects of nanoartifacts and their use. In terms of the social aspect of nanoartifacts, it is yet unclear how the emergence of nanotechnology will affect social relationships (see e.g. Roco & Bainbridge 2002). Already now there are concerns about the possibility that nanotechnology will enhance the gap between those that have and those that do not have access to new technologies.

(11) As for the economical aspect, business corporations are faced with great uncertainties when making decisions about whether or not to invest in nanotechnological developments (at least, as far as the long-term future is concerned; at the short term there are fairly detailed expectations about possible industrial applications).

(12) Next in Dooyeweerd's ladder of aspects is the aesthetical aspect, which is the aspect in which the issue of harmony or disharmony is the key issue. Here too there are great uncertainties. Will nanoartifacts function in harmony with the artifacts that have been produced in more traditional ways? This point was raised by Langdon Winner in his testimony to the committee on Science of the US House of Representatives.[6] Perhaps that question presses even more when we consider the option that these nanoartifacts show characteristics of life, and yet are known to be the result of an artificial process.

(13) The juridical aspect raises questions with respect to developing legislation in a situation where the technology is not yet well known. What kind of laws should be defined in such a situation? Can laws be used to prevent undesired practices in

an early phase of a technological development? Usually legislation lags behind, and undesired practices have already had the chance of developing. It would be better to prevent such practices than trying to get rid of them once they have already emerged. Could nanotechnology be one of the first examples in which legislation is not just an effort to clean up the mess? But how can we determine what legislation would be appropriate?

(14) Also in the ethical aspect discussions are difficult because of the uncertainties about what nanotechnology will look like in the future. Several possible ethical issues have already been identified: the possibility of nanotechnology running out of hand and causing life-threatening situations (this in fact is the basis of Michel Crichton's (2002) novel *Prey*), and possible privacy problems when miniature equipment can be made and installed without being visible for the naked eye. But at this stage it is difficult to develop concrete ethical guidelines for nanotechnological developments.

(15) Finally we have the pistic aspect, which refers to beliefs and convictions that people may have with respect to technological developments. Nanotechnology offers a nice example of the important role such beliefs can have. Nanotechnological developments are often strongly pushed by strong beliefs in the far-reaching promises that are made by some nanotechnology visionaries. They suggest that nanotechnology in the end will offer us the means for the ultimate control over our world, because we can manipulate things at the most fundamental level. The pistic aspect raises the question which drives people to be involved in nanotechnology. Is it a matter of having control for the sake of exerting power over others or over nature? Or is it a matter of serving other people? Or is it a matter of responding to God's call to humans to serve Him by bringing into further deployment what He created? The answers to such questions can also be very determining for one's attitude towards the issues that have been raised by considering the previous aspects.

Integration of Aspects

An issue that is raised by the considerations above is the integration that is needed to make informed decisions about nanotechnological developments. According to Dooyeweerd integration of knowledge of the various aspects takes place when an engineer is involved in practical design and problem solving work. He/she takes notice of scientific knowledge referring to the various aspects and then tries to take all of that into account in one comprehensive decision. In order to gain that scientific knowledge people in the various scientific disciplines have each abstracted one aspect from the full complex reality and focus on a description of the regularities and particularities of that aspect. The engineer when using that knowledge then moves back to the 'level' of the full complex reality when making his/her design decisions. But there is also a second way of knowledge integration, which is still at the level of scientific, abstract considerations. It is what we usually call interdisciplinarity. At that level we seek abstract and general knowledge not with respect to one aspect (as in a specialized discipline) but with respect to more than one aspect. Interdisciplinarity is often mentioned as a characteristic feature of nanoscience and nanotechnology. A proper philosophical conceptualization of interdisciplinarity is not yet available (Margareth Boden's [1997] well-known taxonomy of levels of interdisciplinarity is more sociologically oriented than philosophically). Dooyeweerd has not systematically reflected on how knowledge about the various aspects can be brought together in true interdisciplinarity. He does have some notions that may be useful to explore for the purpose of conceptualizing interdisciplinarity. For example, he claims the possibility of analogies between the 'laws' in the various aspects. These emerge as a result of anticipations and retrocipations between the aspects. Anticipation means that a concept in a certain aspect contains a reference to a concept in a later aspect (for example, the concept of emotional value in the psychic aspect refers to the concept of value in the economic aspect). Retrocipation, likewise, means that a concept in a certain aspect contains a reference to a previous aspect (for example, the concept of profit margin in the economic aspect refers back to the concept of margin in the spatial aspect). Because of such relationships between concepts in different aspects, analogies between laws can emerge. For instance, we find conservation laws in several of the aspects. Such analogies could be the basis for finding regularities that would hold for more than one aspect and thus could contribute to interdisciplinary knowledge. But this needs much further explication in order to be fruitful for conceptualization of interdisciplinarity. One of the fields that can be drawn from here is that of systems sciences. In that field analogies between systems in various aspects (e.g. ecosystems in the biotic sphere and mechanical systems in the physical aspect, but also social systems in the social aspect) are studied and conceptualized.

Final Remarks

A survey of what the aspects may mean in the case of nanotechnology has shown how complex a non-reductionist description of nanotechnological developments will be. The survey raises more questions than it answers. One could also read the previous considerations as an agenda for further philosophical reflections on nanoscience and nanotechnology.[7] A challenge for further reflections is certainly to seek out the consequences of the different 'laws' that we can find in the different aspects, and—as stated above—the integration of knowledge of those 'laws.' Perhaps at this stage the identification of relevant philosophical questions is more important than providing the answers to such questions. Probably the content of this issue of Techné will reflect that at the moment we do not have that many answers yet. But in that situation setting up a proper research agenda is important and the Dooyeweerd approach that was described here can be a contribution to that, as well as to the later effort of seeking answers to the research questions.

References

Bergvall-Kåreborn, B. 2002. *A Multi-Modal Approach to Soft Systems Methodology*. Luleå University of Technology, Luleå..

Burkhead, L. 1999. *Nanotechnology without Genies*. www.geniebusters.org.

Checkland, P. 1981. *Systems thinking, systems practice*. Wiley: Chichester..

Crichton, M. 2002. *Prey*. HarperCollins: London.

Boden, M. 1997. "What is interdisciplinarity?" in Cunningham, R. (ed.), *Interdisciplinarity and the Organization of Knowledge in Europe*. European Community, Brussels.

Dooyeweerd, H. 1969. *A New Critique of Theoretical Thought, Vols I-IV* (transl. from Dutch by D.H. Freeman and W.S. Young). The Presbyterian and Reformed Publishing Company, S.l.

Drexler, E. 1986. *Engines of Creation*. Anchor Press, New York.

Kroes, P.A. & Meijers, A. 2000. "Introduction: a Discipline in Search of its Identity", in: Mitcham, C., Kroes, P.A. & Meijers, A.W.M. (eds.), *The empirical turn in the philosophy of technology*. JAI Press, Stanford.

Mitcham, C. 2002. 'Do Artifacts Have Dual Natures? Two Points of Commentary on the Delft Project, *Techné* 6(2): 9-12.

Nijhoff, R.A., Strijbos, S., Bergvall-Kåreborn, B. & Mirijamdotter, A. (eds.). 2003. *Towards a New Interdisciplinarity. Proceedings of the 9th Annual Working Conference of CPTS*. Centre for Philosophy of Technology and Social systems, Amersfoort, the Netherlands.

Roco, M.C. & Bainbridge, S. 2002. *Societal Implications of Nanoscience and Nanotechnology*. Kluwer Academic Publishers, Dordrecht, the Netherlands.

Sarlemijn, A. 1993. "Designs are Cultural Alloys. STeMPJE in Design Methodology." in Vries, M.J. de, Cross, N. & Grant, D.P. (eds.), *Design Methodology and Relationships with Science*. Kluwer Academic Publishers, Dordrecht, the Netherlands.

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[1] In this paper the concept of complexity will be analysed differently from the way it is done in complexity research in the context of the theory of non-linear systems and computational theories of complexity. A more qualitative approach will be used here.

[2] More information on this project can be found at www.dualnature.tudelft.nl/

[3] Because of his Calvinist background, we speak of 'reformational philosophy'. More information can be found on www.isi.salford.ac.uk/dooy/ and home01.wxs.nl/~srw/

[4] Some information on his person and work can be found at: home.planet.nl/~srw/nwe/vollenhove/kok.html.

[5] I will assume that elsewhere in this special issue a global description of nanoscience and nanotechnology has been presented already.

[6] See www.rpi.edu/~winner/testimony.htm.

[7] Probably several of the issues that have been mentioned here will also feature in other articles in this Special Issue of Techné. Several of the issues also feature in the University of South Carolina research agenda on the philosophy of nanotechnology (see www.cla.sc.edu/cpes/nirt/nirt200112/nirt.html). It is also possible that some issues have not yet become the focus of philosophical reflections, and in such a case the reward for applying Dooyeweerd's approach is that we may start appreciating the relevance of such issues now.

Feynman Unprocessed

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Perfectly Reasonable Deviations from the Beaten Track: the Letters of Richard P. Feynman, edited by Michelle Feynman. New York: Basic Books, 2005. 486 + xxiii pages. $26 in hardcover.

It would be quite a daunting task to try to master everything written by and about Richard P. Feynman. There are his specialized physics books; his *Feynman Lectures on Physics* and similar works for larger audiences of college students; his popular essays and lectures; his witty, irreverent autobiographical masterpieces; two major biographies; and lots of other contributions by other authors. The specialized works are of course beyond the understanding of many readers, but the popular essays and autobiographical stories are a delight to many, whether specialist or not. His scientific work earned him the Nobel Prize in Physics, but his desire and ability to communicate with non-experts turned him into a much greater celebrity than most Nobel laureates ever become.

Some of Richard Feynman's most famous works, e.g., *Surely You're Joking, Mr. Feynman*, include pieces that are obviously transcripts of interviews and conversations which have been edited to minimize the difference between the spoken and the written word. Truly they are a pleasure to read, yet they contain enough signals and cues of casual verbal expression to reveal that his role was sometimes not to write, but to talk. *The Meaning of It All*, for example, is a series of lectures that retained all their verbal stylistics, making them seem windy and ragged. By contrast, Feynman's colorful books about Feynman apparently used copy editors to good effect to shape the man's spoken words into a text for his reader-consumers. He himself said it effectively: "I don't speak writable English" (letter of 24 January 1977).

One can see this most clearly in the case of "Infinitesimal Machinery," a 1983 lecture at the Jet Propulsion Lab that was videotaped, and then published ten years later, after his death. The audio-visual record shows that the lecture is very informative, but also somewhat rambling, almost disjointed, with sudden inspired digressions. The presentation is almost zany, and the scientists in the audience behave as if they are at a comedy club when a celebrity stand-up comic is performing. Not surprisingly, the text version of "Infinitesimal Machinery" is much more linear. It is far from dull, but it is definitely processed to convert the performance from more entertainment to more scientific information.

I am not hinting that there is anything deceitful or improper about copy-editing Feynman for his readers. On the contrary, the legions of Feynman fans ought to appreciate this way of bringing his words and stories to us. My point, rather, is that reading the processed Feynman makes one wonder if there ever was an *un*processed body of his writing, and what it might have been like. It would not have to be a cryptic book with a secret code that supposedly revealed the true essence of the man, as if his true self had been concealed all these years. His life was so well known that it would be silly for anyone to put forward a crypto-bio-psychological theory that claimed to discover the real Richard Feynman. No, the desire to see a body of unprocessed Feynman writing has a simpler, more modest reason behind it. This guy was lovable, and perhaps one could extend and prolong the way we enjoy him if we could read his heart-felt letters with little or no copy-editing.

That is the great value of *Perfectly Reasonable Deviations from the Beaten Path*. It contains no great secrets about how to shape your mind into that of a brilliant scientist, nor any manual about how to become a celebrity, nor how to acquire the irreverent wit that he perfected. It is, rather, a kind of friendly front-porch visit with someone you already know and like, if you already know Feynman's books about Feynman.

I have had my front-porch visit with him, which is to say that I have enjoyed reading this book. Instead of giving you a one-paragraph summary judgment that tells you how you ought to enjoy it, I give you a taste of the more interesting passages and letters so that you can align this book with whatever other works of his you have enjoyed.

Loving Arline

Much of the early part of *Perfectly Reasonable Deviations* concerns Feynman's marriage to the former Arline Greenbaum. She had a serious case of tuberculosis before they married, and Feynman's parents were less than enthusiastic about their son marrying a sick woman. In a letter to his mother in June 1942, Feynman showed himself to be clear-eyed and passionate about marrying her anyway: "I want to marry Arline because I love her—which means I want to take care of her. That is all there is to it. I want to take care of her."

Indeed he did. Most of the correspondence from his Manhattan Project years [1943-45] shows that he devoted enormous attention to her comfort, her happiness, her diet, and her other needs. Remember that Arline lived in a clinic in Albuquerque while he worked at Los Alamos. They had tried briefly to have her stay at the hospital at Los Alamos, but that quickly turned out to be a disaster (February 1945). The base hospital could not give her the care she deserved. He went to see her most weeks and also wrote several times a week. His letters also reveal that he was trying to understand tuberculosis (7 February 1944), and investigating whether a new therapy would cure her (December 1944), and lovingly prodding her to eat enough to keep up her weight.

In one sweet passage, he describes to her the delights of picking locks—a well-known element of the Feynman legend—and writes this (4 April 1945): "I like puzzles so much. Each lock is just like a puzzle you have to open without forcing it. But combination locks have me buffaloed. You do too, sometimes, but eventually I figure you out. I love you, too."

Arline Feynman passed away on 16 June 1945. While it is profoundly sad that a nasty disease robbed this man of the woman he passionately loved, I must say that anyone who is seriously ill ought to have a spouse as dedicated as he was to Arline.

Sixteen months after her death (17 October 1946), he dealt with his grief by writing her one last love letter. This, too, is a profoundly moving message, but he ends it with an impish twist: "Please excuse me for not mailing this—but I don't know your new address."

Manhattan Project

The knowledgeable Feynman aficionado is familiar with his brash irreverent recollections of his work at Los Alamos, like the time he prevented the Oak Ridge National Lab from blowing itself up. His private letters from that time, however, are very different. He is full of admiration, not for himself and his triumphs, but for the great scientists who lead the project. He works late, sleeps late, then works late again. His work proceeds with excruciating trial and error.

Often he is far from confident about his contributions. Here he writes to Arline on 22 March 1945:

> Nobody knows what's going on except me and the guy with the busted leg [i.e., his group leader]—and I don't know it so good. Hence I was up from 8 AM Tues. morning to 3 PM Wed. night, 31 hrs. and by that time the new problem was running smoothly. And where were we when I woke up? Exactly where we were when I went to sleep! Somebody made an error 15 min. after I left and we had to go back, correct it, and start over from there. That is why I have to work so hard.

Feynman's describes the Trinity test at Alamogordo in a letter to his mother (9 August 1945). In it you read his vivid portrayal of the anxieties of the scientists, including himself, then the awe he felt at the blinding sight and thunderous sound of the explosion, and finally the wild celebration of the happy scientists. He expressed no Oppenheimer-like moral conflict. On the contrary, "everything had worked as well as anyone could have dared to expect…It is a wonderful sight from the air to see the green area [that is, sand turned to glass by the heat of the bomb] with the crater at the center, in the brown desert."

Then and later he said that using the atomic bomb in August 1945 was justified because it helped to end the war. After the war he seemed to have stayed on friendly terms with both Oppenheimer and Teller; his letters contain no evidence that he took sides in the bitter investigation that humiliated Oppenheimer.

Resignation

The episode of Feynman's resignation from the National Academy of Sciences is the least flattering part of the book. When an assistant business manager sent him a note saying he was two years behind in his membership dues, he replied with a check to pay what he owed, plus a curt note on the bill saying "I have found that I have little interest in the activities of the Academy, so would you please accept my resignation as a member" (9 November 1959). This looked, of course, as if he was leaving the NAS in a fit of petulance, that is, resenting that he had been billed for what he owed. It alarmed Detlev Bronk, President of the NAS, who asked him to reconsider. Feynman explained that he was resigning because he was uncomfortable with the Academy's elitist situation. One of the activities of the members was to select new members. This he considered "a form of self-praise…How can we say only the best must be allowed in to join those who are already in, without loudly proclaiming to our inner selves that we who are in must be very good indeed" (10 August 1961).

As you decide for yourself whether closed-membership academies are legitimate, notice the next development. Bronk tried to persuade Feynman not to resign, and he emphasized that the NAS conducted some worthwhile activities that should interest him—in other words, there was more to its life than admitting some people and rejecting others. Feynman, however, insisted on resigning, but he framed his feelings as "entirely personal and reflect in no way on my opinion of the Academy" (1 July 1968). This line of correspondence went on for years.

As I read the letters back and forth on this incident, it seemed that Richard Feynman was trying to have it both ways. He objected to NAS's elitist habits, and he used the dramatic decision to resign as a way to express his objections, but did not want this decision to be seen as a political protest. A mere personal idiosyncrasy, as he would have one see it.

How could it *not* be a political protest, and how could anyone else see it otherwise?

The other possibility, going back to the bill from the assistant business manager, is that Feynman reacted rashly, but then was too proud to see that he had been too rash. This way it would indeed imply nothing about his respect for the National Academy of Sciences. It would, however, indicate something about his inability to see that he had made a mistake that could have been corrected, especially since Bronk and a later NAS president, Philip Handler, graciously offered him reasons to remain a member.

Either way, the episode of the resignation shows us one of the few occasions when the power of Richard Feynman's great mind was less than the consequences of his impetuous words.

Truth and Beauty

Those of us who are constructivists, relativists, and other sorts of post-modernists are particularly curious to see whether Richard Feynman wrote anything that might corroborate our paradigms. Our question is answered with a short, stark, unambiguous "No." Feynman embraced a hard simple positivism in his scientific work, and he did so consistently.

It is true, of course, that he was comfortable with many sources of inspiration; and that he wanted us to know that science is fun; and that he showed us how scientists can be charismatic. When young people or their parents wrote to him to ask how to plan a career in science, his advice was that would-be scientists should follow their own passionate curiosity, as opposed to planning a long-term linear path. You read this again and again in those sorts of letters.

And yet, as he became famous and received letters from scientists and fans and cranks, he repeatedly advocated the same clear and simple formula for doing science:

1. *Scientific truth is international*. He objected to being labeled an "American" scientist or a "Jewish" scientist because, in his thinking, this violated the transnational essence of science.

2. *The reason for doing science is to satisfy a curiosity about nature* (which he usually capitalized as "Nature.") When he heard that the poet W.H. Auden wanted to know what scientists "want the knowledge for," Feynman replied that "We want it so we can love Nature more." Too few people, he complained, understood "the emotions of awe, wonder, delight and love which are evoked upon learning Nature's ways…My lament is that a kind of intense beauty that I see given to me by science, is seen by so few others" (24 October 1967).

In a 1959 television interview, he was asked how he took into account the social and economic implications of science. He declined to discuss that topic: "The reason that I do science…is…not the usual motivation for helping human beings. The main motivation is the curiosity and interest to find out about the world we're in" (pages 419-420). He easily conceded, of course, that scientists see the consequences of their work, but he adamantly bracketed their motivations from the applications of that work which the rest of the world experiences.

3. *The experiment is the great and final adjudicator of truth*. Scientific ideas must be focused into predictions and experiments, which are almost always in mathematical language. When asked about the "scientific method," he wrote "the only principle is that experiment and observation is the sole and ultimate judge of the truth of an idea. All other so-called principles of the scientific method are by-products of the above" (30 April 1963). Again, twenty years later: "I like science because when you think of something you can check it by

experiment; 'yes' or 'no', Nature says, and you go on from there progressively. Other wisdom has no equally certain way of separating truth from falsehood" (28 February 1983).

With that as *his* philosophy of science, he declined to engage in broader discussions of philosophy of science or the other humanities-based investigations that we now call Science and Technology Studies. In his influential 1961 article on "The Future of Physics," he spoke of protecting science from "the encroachment of professional philosophers and fools…Since they are absolutely unable to make any predictions, we see that their philosophy does not have real understanding of the situation" (p. 438).

For the most part, he expressed admiration for other people's appreciation of art, poetry, and other aesthetic pleasures, but he kept those tastes at arm's length from his own love of science. When someone suggested that Feynman's famous hobby of playing the bongo drums was a way for him to make himself well-rounded by balancing his music with his science, he reacted angrily:

> The fact that I beat a drum has nothing to do with the fact that I do theoretical physics. Theoretical physics is a human endeavor, one of the higher developments of human beings—and this perpetual desire to prove that people who do it are human by showing that they do other things that a few other humans do (like playing bongo drums) [original brackets] is insulting to me. I am human enough to tell you to go to hell (4 January 1967).

We see that Richard Feynman was extremely generous whenever he was asked to share his views with nonexperts, to their great benefit. But we also see that he required you to come to his views on science on his terms, especially in the media interviews. How then could this citizen-scientist interact with nonexperts who did not possess his understanding of science? Could these citizens too have a role in science policy?

Yes, yes, I recognize that I am asking a man who passed away in 1988 to speak to the issues of 2005. Embryonic stem cell research, nanotechnology, genetically modified organisms: these and many other topics show us that nonscientists too have a stake in the outcome of science policy debates. They also have roles to play when science policy is created through legislation, litigation, lobbying, appropriations, regulations, referendums, and other procedures, none of which are under the exclusive control of scientists. The contributions of someone like Richard Feynman are extremely valuable, but our boisterous interest-driven democracy does not give scientists a monopoly on the making of science policy. So, could the nonexpert fit into Feynman's world?

Citizen

With his intense dedication and brilliance, Richard Feynman was a very formidable citizen-scientist. One comment from 1959 points to the idea that citizen-*non*scientists have a contribution to make:

> It seems to me very difficult for citizens to make a decision as to what's going on when you can't say what you're doing. And the whole idea of democracy, it seems to me, was that the public, where the power is supposed to lie, should be informed. And when there's secrecy, it's not informed (1959 television interview).

Unfortunately, the context of this statement shows that Feynman was arguing against the kind of cold war secrecy that most scientists despise, which does not necessarily translate into advocating democratic mechanisms that include nonscientists in science policy. Feynman's work in the process of selecting science textbooks for California public schools, with some passages from that work included in this book, shows that he was more than willing to rub shoulders with the nonscientists who choose which schoolbooks our children read. It also shows how exasperated he was by the textbooks that came before him and his fellow readers.

Even more telling, however, was his 1986 experience with the commission investigating the causes of the *Challenger* tragedy. In a long eloquent letter to his wife and daughter on 12 February 1986, Richard Feynman burned with anger about the politics of the *Challenger* investigation. He accepted the mandate of the commission in good faith and worked at full throttle, but found that the chair of the commission, William Rogers, was overly concerned about not rocking the boat, not leaking to the press, not criticizing the ways NASA made decisions, and so on. We then see that Feynman was clever, but not obnoxious, in finding ways to circumvent Rogers and so discover the technical information that Rogers preferred to avoid. The most memorable event of Feynman's work on the *Challenger* commission was his dramatic demonstration, on television, of the way the booster rockets' O-rings failed in cold temperatures. His pursuit of the serious flaws in NASA decision-making was much less sexy, but it constituted a much more substantive contribution to our understanding of the reasons behind the tragedy, and he knew that clearly.

In the end, Richard Feynman was disgusted with the behind-the-scenes politics that he saw in those days. "Nothing short of a subpoena from Congress will get me to Washington again," he wrote after the commission was finished (5 December 1986).

Privately Readable Deviations

The title of this collection comes from a memo that Richard Feynman wrote to the California State Curriculum Commission on 13 April 1966. Regarding a fifth-grade science textbook, he objects that "the teacher's manual doesn't realize the possibilities of correct answers different from the expected ones and the teacher instruction is not enough to enable her to deal with perfectly reasonable deviations from the beaten path." Since that phrase is used to label this record of his life, presumably it is meant to remind us that Feynman himself was different from other people—no kidding—but that his eccentric brilliance was perfectly reasonable in its own way.

I find this choice of title to be peculiar. Richard Feynman's idiosyncrasies were fully celebrated in *Surely You're Joking, Mr. Feynman* and *What Do You Care What Other People Think?* But this collection of his letters does not really continue the "eccentric genius" tone of those two earlier books. Instead it shows a loving husband, loving father, hard-working scientist, friend to strangers, frustrated citizen, loyal friend, and other admirable parts of his personality that come to life even when the public is not watching. Although there is plenty of wit in these letters and there is no shame when his idiosyncrasies arise, a reader looking for the classic Feynman-the-entertainer will be surprised by the content of this book. I feel strange saying this, but I would not recommend *Perfectly Reasonable Deviations* as a reader's first introduction to this man. *Surely You're Joking* and *What Do You Care* represent a good way to get hooked on Feynman, after which *Perfectly Reasonable Deviations* lets us see a more private side of him, and that sequence serves his memory very well. I fear that if one were to meet him first in this collection of letters displaying the anguish of Arline's death, the patience with which he explained things to strangers, the frustrations of the citizen-scientist, and similar sentiments, and then later read the two collections of anecdotes, then the Feynman of the earlier books would subsequently look like one of those entertainers who is a little too eager to please his audience by exaggerating his own eccentricities.

Let us finish with the problem of "writable English," as he called it. A letter to his mother, Lucille Feynman, on 30 August 1954 shows a man painfully struggling to make his words come out right. He tries to tell her that she has everything that money can't buy, and that he will provide for all of her material needs. In saying this, he racks up one garbled cliché after another, e.g., "wealth is not happiness nor is swimming pools and villas. Nor is great work alone reward, or fame." Ouch. What his mother really wants, he admits, is for him to write more often. He promises he will. A note from the editor, his daughter Michelle Feynman, says that the problem of the son who wrote too seldom was solved, not by a quantity of letter-writing, but by having the mother move to Pasadena to be near her son.

If that was Richard Feynman's unwritable English at its most difficult, it did not last forever. There was nothing awkward or problematic with the writing in Feynman's letters by the mid-1960s. Maybe this reflects his self-confidence; or maybe many years of writing many letters led to a distinctive and effective style. At any rate, some of the letters from the last twenty-five years of his life are great documents, especially those in which he has to explain something—not necessarily something scientific—to his reader. The letter to his wife and daughter about the politics of the *Challenger* investigation (12 February 1986) is especially memorable.

I do not assume that the letters in *Perfectly Reasonable Deviations from the Beaten Path* are entirely free of copy-editing. There could well be some, and of course Michelle Feynman must have had to exclude some items when she included the ones we see here. But almost all of these were written with no expectation that they would be published someday—remember the sweet letter to Arline after she died—so they are free of the sense that Feynman was writing with a third-party reader (i.e., you or me) looking over his shoulder. As such, Feynman unprocessed is a lovely complement to the side of him we see in his delightful autobiographical works.

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