

Centre and Periphery of Nano—A Norwegian Context

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Abstract This work describes the nano field in Norway as currently emerging in the dynamics between two forms of nano research activities described along a centre-periphery axis. 1) There are strategic research initiatives committed to redeem the envisioned potential of the field by means of social and material reorganisation of existing research activities. This activity is seen as central as it is one of our premises that the standard circulating nano vision implies such a work of reorganisation. The fact that nano is often taken as a paradigmatic example of the shift from Mode-1 to Mode-2 research, supports this assumption. 2) In parallel to this activity, a wide variety of research projects pursuing nano strategies are being funded. We regard such research activity as peripheral in so far as the activity is not marked by being committed to the circulating nano vision, as may often be the case. In the

process of reorganising, this article argues, the research activity at the periphery provides a crucial arena for discussing and validating what is to be achieved through the work of reorganisation that takes place at the centre. Our analysis is informed by two Norwegian cases. We examine a major nano research initiative at a Norwegian university as a centre and a research project utilising nanoparticles in fish vaccines as a periphery.

Keywords Centre and periphery · Conceptualisations of nanotechnology · Mode-1 and Mode-2

What is Nano?—Once Again

It has proven difficult to clarify what nano is as a scientific field. The question of what nano is is complicated as it is entangled in normative questions of what the point or the purpose of the field is. Why is this activity called nano worth pursuing, what justifies the investments and the promises being made, the claims of uniqueness or added value of subsuming apparently disparate activities under the heading of nano? Such questions reflect not only concerns of the scientific communities but also legitimate concerns of various stakeholders like politicians, funding agencies and NGOs.

The questions of what nano is have been particularly importunate since the difficulties of clarifying what nano is in turn reflects transitions in norms that underlie judgments of worth assigned to scientific

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fields as such. Nano constitutes an arena for revisiting basic ideals for knowledge producing activities. A transition in such ideals follows from what has broadly been suggested and discussed in terms of a shift from Mode 1 to Mode 2 [8, 21] or as a shift from academic to post-academic science [35]. We situate the controversy on how to conceptualise nano against a background of these analyses. What nano is, or aspires to be, we argue, needs to be articulated and examined in light of these trends towards Mode-2 research conditions. Following the way we situate nano as a field that is part of these trends, we identify a vision of the field of nano.

This nano vision, as we shall return to shortly, holds out expectations of what can be achieved in the long run—achievements that are conditioned by high investments and reconstructions of existing research systems. In the current situation, in times where such reconstructions are advocated and attempted carried out, the field of nano appears to emerge in the dynamics of what we describe as a centre-periphery axis. What we describe as activities in the periphery of nano provide an arena for evaluation of what is to be achieved by the reorganisation prescribed by the nano vision. As a point of departure for these discussions we clarify how nano may be conceptualised respectively from a Mode-1 and a Mode-2 perspective.

Seen from the perspective of Mode-1 research conditions, academic driven research is valued since it is considered to condition genuine knowledge seeking research activity. Attempts to clarify the characteristics of a given field would accordingly have a focus on the epistemic specificity of the field's research potentials, as for instance made possible by novel discoveries, innovative technologies, methodologies or theories. In the case of nano, most attempts to define the field are of this kind, as they refer to the engineering of nano-structures that utilise specific properties exclusively delivered through engineering at the nanoscale (often, but not necessarily, specified in the range up to about 100 nm). The following definition provides an example of the sort, a definition presented to us by researchers in the nano-vaccine project we have studied:

‘The design, characterization, production, and application of structures, devices, and systems by controlled manipulation of size and shape at

the nanometer scale (atomic, molecular, and macromolecular scale) that produces structures, devices, and systems with at least one novel/superior characteristic or property’ [3].

The controversy of nano bears witness of the difficulty of such definitions. How to capture the exclusive ‘nanoness’ of the variety of projects that run under the heading of nano? That is—why do such definitions capture something of importance, justifying the isolation of various activities as something called nano? Failing to see how such definitions may provide a normative line of demarcation for a field, some critics even conclude that nano is hyped, that it is an empty signifier, a bubble, a fashion or simply a funding strategy [5, 14, 29, 34]. What is challenged here, one could say, is the scientific integrity of the field of nano. Accusations of hype reveal disappointed expectations of what it takes of a field to be referred to as a scientific field. The field has come to be presented in ways that does not seem to be worthy of our trust. The questioning of the scientific integrity of nano began shortly after the term nanotechnology first appeared in the 1970s [29] and it has endured even though we in parallel have witnessed a dramatic growth in number of nano research institutions [28], nano-publications [17], nano-patents [11], nano-conferences, nano-journals and even nano-products.

Seen from the perspective of Mode-1 research, then, it makes sense to focus on research potentials of engineering at the nanoscale when seeking to clarify what nano is. Such definitions then, have a demarcating function, as they define the type of activity that is to be called nano. Such definitions however, call for some justifications of why such activities are worth pursuing at a generic level: what is the added value of describing various projects utilising what is defined as nano strategies under the same heading? Investigations of what nano is, which depart from definitions of the kind given above, however, have apparently not resulted in answers of the sort. On the contrary, the nano label on many research activities that run under the heading of nano appears incidental in so far the projects might as well have been inscribed into a number of different fields.

In talking to a range of different researchers, we were struck by the fact that the ‘nano’ concept did not appear to serve a specific analytical purpose in their research. It was for instance not referring to, to use

one of Rheinberger's [25] terms, an epistemic object or research system, that were not yet fully established or articulated by the nano term. Their research could as well be described under other headings; it was difficult to see the added value of the concept of nano. Observations like these, gave rise to our identification of the periphery of nano. In some research communities, it simply appeared to be common knowledge that nano projects were, in most cases, largely a question of renaming. Even if their work certainly could be described as nano research, according to formal definitions, the fact that it was named as nano, they emphasised, did not make a difference for their research activity.

In other research communities however, nano appeared to play a decisive role. The term appeared to communicate something of vital importance for the community; the notion expressed a vision for a particular powerful research strategy worth pursuing. This vision, we suggests, reflects judgments of worth of a scientific field that become visible as we consider nano as entrenched in contemporary trends described among other things as a shift to Mode-2 research conditions.

An important feature of the trends towards Mode-2 research concerns the way context or problem driven research is valued and nurtured. In contrast to academic driven research, context driven research is, so to speak, geared towards application from the very beginning. Although these changes have not necessarily been welcomed as desirable, the rise of the nano field has been taken to represent a paradigmatic exemplar of the reality of such changes (see for instance [2, 13, 20, 33]). As a result, according to these analyses, novel large and high priority fields like nano impose radical, and possibly even irreversible, changes in the way science is performed, organised and managed. We do not seek to make claims to whether or not these changes are desirable, but we consider it to be an open question. What we claim, however, is that the vision of nano is more appropriately expressed in terms of Mode-2 research. We will in the following take a look at standard presentations of the field of nano in order to substantiate this claim.

As Shew and Baird have noticed, a particular story tends to be reproduced in various forms as nanotechnologists present the field. They call it the 'standard story' [29, 30]. The standard story of nano

is a story of the scientific and industrial potentials of nano inscribed into a story of the history of the scientific field. It is a story of the kind we often find in scientific textbooks, as described by Thomas Kuhn and others. Such stories are first of all historical reconstructions that, although often not accountable with respect to historical facts, play a legitimate role in capturing crucial features of the current state of the art of the field for the purpose of introducing it to newcomers. The standard story, Shew and Baird observes, typically start with Feynman's famous talk 'There is plenty of room at the bottom', which is typically presented as an inspiration for scientists to develop technological infrastructures that enable new opportunities for design at the atomic and molecular level. The developments of stunning instruments like STM and ATM, as the story typically goes, was not only inspired by Feynman's vision but also inspired scientist across all standard disciplines of science to explore potentials of intervening at 'the bottom' of material structures. The stories come in various forms, but the point of these stories, as we read Shew's and Baird's argument, is to draw our attention to revolutionary commercial opportunities of the unique properties released in creating interdisciplinary venues for controlled technological manipulations at the nanoscale.

There are three connected elements of the standard story account of nano. These three elements are for instance expressed in a condensed form in the opening of the influential report, *Societal Implications of Nanoscience and Nanotechnology*, written for the US National Science Foundation just after the National Nanotechnology Initiative (NNI) was established:

'A revolution is occurring in science and technology, based on the recently developed ability to measure, manipulate and organize matter on the nanoscale—1 to 100 billionth of a meter. At the nanoscale, physics, chemistry, biology, materials science, and engineering converge toward the same principles and tools. As a result, progress in nanoscience will have very far-reaching impact' [26].

This excerpt succinctly connects three important themes: 1) A current revolution follows novel nanoscale sensitive technologies which are conditioned by 2) a convergence of traditional disciplines that in turn

3) will have far-reaching socioeconomic impact. The standard story, then, revolves around nanoscale sensitive interventions, but communicates an understanding of nano that is more oriented towards context of application as compared to typical definitions of nano that provide a focal point for controversies of how to define the field. The three-component standard story does not only address a broader political, industrial and public audience, but also scientific communities that aim at promoting the field at a generic level. A centre of nano, we suggest, is held together by these three connected elements. The combination made it possible to stabilise something called nano, build expectations of economic potentials of high investments and joint efforts of dispersed scientific activities. At the centre we find initiatives, programs and strategies committed to the realisation of this standard nano vision. The vision calls for a reorganisation of how research is done. It is a vision that carries promises of improvement following such a reorganisation. We do not question the scientific status of the vision, that is, the legitimacy of the vision. But, like any other scientific visions, the expectation expressed in the vision need not be fulfilled. At present, we claim, nano research activity at the periphery provides a crucial test arena for validation of visions expressed at the centre.

Individual projects that are pursuing nano strategies constitutes arenas for validating discussions of what one can possibly achieve if research is reorganised in accordance to the prospects of the nano vision. This critical potential follows from the way experimental sciences are anchored in epistemic commitments to the dynamics of experimentation. As Hans-Jörg Rheinberger [25], Karin Knorr-Cetina [15], Ian Hacking [9] and others have pointed out, experimentation is an open ended activity marked by the pursuit of building robust reproducible laboratory settings, an ‘experimental system’, through which research questions themselves may be articulated and clarified. Experimental systems are not only crucial for the identity of the field, they are also self-vindicating units. The nano projects, which we understand as being in the periphery, have a weak nano identity in the sense that the projects may as well have been inscribed into other field categories. Most concrete nano projects may reside in the periphery in this sense. They apply nano strategies without being committed to them as such. The nano strategies are

part of what is adjusted and possibly even abandoned in the self-vindicating process of building workable experimental systems for the resolution of research questions being formulated in the same process. The periphery, therefore, plays a crucial role in exploring the validity of the generic nano vision of the centre. While peripheral projects may be inscribed into nano as it is conceived of at the centre, they primarily remain committed to the resolution of specific scientific questions. It is in the periphery that the promises of nano strategies ultimately are to make a significant difference as nano strategies merge into a range of different research contexts—i.e. the nano-revolution. But it is also in this very research process that the expectations of the potentials of nano need to be demonstrated. The peripheries, we suggest then, constitute important arenas for proofs of concept within nano as successful nano projects may serve the function as model exemplars of the field.

Our centre-periphery model of nano may not only help explain how nano on the one hand has expanded into so many areas of research, technology, and business, while it on the other hand may seem prone to collapse once it is critically scrutinised as a new scientific field along established epistemic measures. Our model may also help explain the difficulty of conceptualising nano by drawing attention to how the nano vision expresses a Mode-2 research vision. While we do not pretend to hold a position from which the future of nanotechnology as a field may be forecasted, we suggest the centre-periphery model as a way to enable an improved grip on some of its significant contemporary dynamics.

Our centre-periphery analysis is inspired by earlier scholarly work analysing how hierarchal centre-periphery structures tie together the scientific communities of a field [12, 27, 32]. The community, given these analyses, functions through power relationships one need to be aware of and pay attention to when scientific truths are communicated and evaluated. Given that decisive developments of a field needs to pass through central sectors of a community, this affects more peripheral sectors as it sometimes induce obedience, imitation and deliverables of subsidiaries.

The centre-periphery dynamics in the case of nano, however, is marked by the fact that the field went global before it had reached a mature state. There has not been, as it were, a centre delivering core knowledge to be consumed, imitated, opposed or

modulated in the periphery. There has not been a clear exemplary centre in which researchers at the periphery could mirror, submit or adjust their professional identity as nano researchers. The centre, in our analysis, has primarily been expressed as a scientific vision that, at least in an early stage, seems to be worked out in particular scientific contexts that appear peripheral.

In our account of the centre and periphery of nano, the relation between centre and periphery can hardly be said to be hierarchal in the sense that the periphery represent a weak imagery of the research activity at the centre. On the contrary, the periphery may play a much more significant role in ongoing verifications and adjustments of the nano vision at the centre.

Two Norwegian Cases

This work is informed by two case studies respectively of a centre and a periphery in a Norwegian research setting.

As a centre, we have examined the NTNU NanoLab at the Norwegian University of Science and Technology (NTNU), located in Trondheim in mid Norway. NTNU NanoLab is a strategic initiative that aims at strengthening NTNU's national position as a centre for engineering and technological sciences by building capacities for nanotechnology research and development. Our knowledge of this case stems from semi-structured interviews, document materials, participation in research seminars and collaboration in terms of being invited to strengthen ethical dimensions of the initiative through research, seminars and teaching. The interviews were conducted from spring 2008 until autumn 2010. They include interviews with nano scientists, toxicologists, strategic coordinators, lobbyists, funding agents and persons involved with the nanotechnology study program.

As a periphery we have examined a research project that aims at using nanoparticles to make more efficient salmon vaccines. This project is located at the Faculty of Biosciences, Fisheries and Economics at the University of Tromsø in Arctic Norway. Our knowledge of the vaccine case stem from semi-structured interviews with the project leader and the project participants as well as structured and unstructured discussions in seminars, workshops and visits of laboratory facilities. The interviews were conducted

in spring 2009. Our encounters with the fish vaccine project stem from an attempt to situate the ELSA research project (in which the present work is funded) in a research context where scientists were both being researched and welcomed to contribute to the research.

Nano at the Centre: A Strategic Nano Initiative

We examine a major strategic initiative for developing nanotechnology research in Norway named NTNU NanoLab. While the NTNU NanoLab is not the only such initiative in Norway, there is no doubt that it takes on a central role in a contemporary Norwegian nanotechnology research landscape.¹ As a strategic research initiative, NTNU NanoLab is not organised, built and adjusted through the work of articulating and seeking answers to specific research questions in a way characteristic of laboratory work. While the initiative hosts concrete nano research projects, NTNU NanoLab itself is better understood as an organisation pursuing a strategic plan for promoting nano research. This includes building clean room facilities, and establishing educational programs, coordinating and facilitating interdisciplinary research activities. As an organisational unit, NTNU NanoLab's objective is not to pursue research but to facilitate the release of scientific and commercial research potentials of nanotechnology. Informed by, and committing to, the vision of the standard story of nano, it takes on a nano identity characteristic for what we identify as the centre of nano.

The Empty Room

In 2002 a committee was appointed by the rector at NTNU at the time, the physicist Eivind Hiis Hauge. The committee included international as well as local nanotechnology researchers appointed for the evaluation and planning of activities within nanotechnology

¹ Initiatives at four institutions (IFE, SINTEF, UiO and NTNU) have been particularly important in the early attempts to establish nanotechnology in Norway. Together, and partly in joint efforts, these received 80% of the 337 mill NOK allocated for funding research within the first period of the program 'Nanotechnology and new materials' (NANOMAT) of the Research Council of Norway.

at NTNU ([22]:2). An ambitious plan for construction of an ‘infrastructure for nanotechnology’, suggested by the committee, was approved by the board of NTNU in March 2005.² The board granted 145 million NOK (about 18 million EUR), representing the largest singular investment ever approved at NTNU. The plan for a new master programme in nanotechnology was simultaneously supported by the resolution. The mission given to NTNU NanoLab, as it is presented in an annual report was to a) ‘coordinate nanotechnological research and capital investments at NTNU’, b) ‘build, equip and operate a new state-of-the-art laboratory for nanotechnological research and education’ and c) ‘promote a new 5 year MSc program in nanotechnology’ ([23]:2). The master programme started in the fall of 2006 and the first part of the laboratory facility was officially opened in May 2007.

In introducing nanotechnology, the committee report reproduces a variant of the standard story of nanotechnology ([22]: 6–7). The story begins with ‘one of 20th century hallmark science lectures’, namely Feynman’s lecture ‘There is plenty of room at the bottom’. The talk ‘put forward a vision of exciting new discoveries related to the manufacture of materials and devices at the nanometer scale’. Feynman predicted the possibility to write the entire Encyclopaedia Britannica within an area of a pinhead, which was confirmed as IBM wrote an IBM logo by means of STM in 1989. This demonstration, according to the report, represents the first of three symbolic milestones in the history of nanotechnology; the top-down approaches. Bottom up approaches, like man-made self-assembled structures, represents the second milestone while the US president Bill Clinton’s financial plan for nanotechnology constitutes the third and final milestone. The report wraps up the story by stating that the

‘[c]ontrol of matter at the atomic or molecular level implies tailoring the fundamental properties, phenomena, and processes exactly at the scale where the basic properties are determined. In this context nanotechnology could impact the production of almost all products produced by humans [...]’ [The impact of

nanotechnology...] ‘would be at least as significant as the combined influence of microelectronics, medical imaging, computer-aided engineering, and man-made polymers developed in the past’ ([22]:7).

In reproducing this standard story of the incredible potential powers of the field, the report communicates the need for some extraordinary measures to be taken in order to promote the field at NTNU. Given its history and aspiration of taking a national lead in engineering fields, NTNU appeared to be a proper place for such an initiative. Hauge is well respected as a visionary driving force for the initiative during his rectorship. In an interview he is portrayed as not being sure what ‘kind of offspring he would bring to life when he fostered the nanotechnology research area at NTNU. But he figures that the new kid on the block will be a healthy one!’[18]. Hauge mediated what appeared to be a strong conviction in many scientific circles: Whatever this thing called nano is, or would turn out to become, it appeared to be worth the efforts and investments it would take to bring the field to life.

We understand the NTNU NanoLab to be the organisational unit established in order to bring the field to life. Its action should be the one of facilitation. As the report stressed, the important function of the staff that were to be hired in the organisation, should be the one of creating multidisciplinary venues that allow for cross-fertilisation of ‘founding disciplines’ of nano (that is basic disciplinary fields like physics, chemistry, biology) ([22]:26). One should not design laboratory facility for specific research purpose of the one to be hired. The task was, to put it in a metaphorical way, to create the empty room designed to release the potential envisioned under the heading of nano.

The clean room laboratory facilities of NTNU NanoLab need to be empty in a literal sense due to the need to control factors like airborne particle contaminations, chemical evaporations, acoustic noise and ground vibrations. The true potentials of these empty rooms however, will only be released if NTNU NanoLab manages to fuse a complementary set of competences. This called for deliberation about what architecture, instruments and organisation of the laboratory would work for potential users of the facilities. Such issues were for instance topics of

² NTNU board meeting. Protokoll 2005. 15.03.2005, S-sak 30/05

series of ‘NanoLab user meetings’, which were instrumental for the organisation’s work of promoting cross-disciplinary cooperation. The response the leader of NTNU NanoLab Erik Wahlström gave to our question of what defines nanotechnology illustrates how important this task is considered to be.

‘What I really think is nanotechnology is when you really work interdisciplinary. When you say—ok—this is nanoscale and it is natural to work interdisciplinary—and we do it too’ [our translation].

One would need to get to the point where this form of collaboration is sparked in the context of the clean room facilities that enable nano research. This emphasis on the need of having researchers collaborating in novel ways is a recurrent topic of the researchers we interviewed. Asked about the vision for bringing about NTNU NanoLab, Hauge responded:

‘Well, you can start by putting in the negative. If you haven’t acquired the infrastructure by which one can operate experimentally on that length scale, then you have in a certain sense defined yourself out of the world. There is so much of the scientific activity within electronics, chemistry, physics, bio taking place there [on that length scale]—that it is...it’s simply out of the question not to [...]. That is my starting point. And when I put it like that, it is in recognition that nano is something generic, it is not a speciality, it is a platform for doing many different things. So—what will turn out to be fruitful, what will be the success or failure of our nanolab, that I do not know—I will not take the role of a prophet. [...] So I really believe that it is the generic character of the field that makes it an imperative to be there [...]. [O]ne thing is what one will accomplish here in terms of research, but one needs to educate natural scientists and civil engineers that can enter the Norwegian society in many functions, and if nano doesn’t exist in Norway on a proper international level, then you are saying to the students that if you want to work in this field, which is very important—ok—then you have to go abroad and study there. So both in terms of research and in terms of education this is absolutely necessary’ [our translation].

Asked by the vision then, rather than pointing at specific research potentials, he draws attention to the need to reorganise how research is done. The task of NTNU NanoLab is the one of responding to state of the art developments in all basic fields as they converge at the nano scale. The point of facilitation then, is not primarily the one of achieving a critical mass for the activity, which of course is crucial as well. The point is not primarily the one of sharing scarce resources either. It is a matter of necessity due to the generic and interdisciplinary nature of the field. NTNU NanoLab is to bring researchers from founding fields together in order to release the potential of what is captured in the vision of nano.

The master program in nanotechnology fits well into this picture. The legitimacy of an educational program for nano would be the one of training a new workforce prepared for nano by having the necessary skills needed for the envisioned future research and industry field of nano. The program provides a multidisciplinary blend of topics as recommended by the 2003 committee. This diversity in turn gave rise to the questions of what scientific unity or industrial needs that justifies the program, a worry being expressed in an evaluation report of the study program [23]. Confronted by this critique, the leader of the study program drew attention to the need for the development of interdisciplinary capacities. The study program should be seen as a long time commitment to nano that includes a strategy for training and recruitment of future researchers able to foster and glue cross-disciplinary research activity. The master program then, appears as a consistent part of NTNU NanoLab’s long term attempt to promote nanotechnology through various strategies of facilitating such activities. The program has so far been seen as a success for other reasons as it has proved to be highly competitive: In 2006, 30 students were welcomed as the first batch in an interdisciplinary nanotechnology master program at NTNU. As many as 1.430 students applied for these 30 places. The nanotechnology students are among the best students in the country measured in terms of how difficult it is to capture one of the 30 places [18]. The program then is successful as NTNU NanoLab has succeeded in recruiting talented young people in a position to demonstrate the potentials of the field. Due to the expectations and prestige of the field there do not

seem to be anyone worrying about their job opportunities—good students are always attractive for the industry, as one of our informants commented. Moreover, as indicated in the program plan of NANOMAT, i.e. the nano funding program at the Research Council of Norway, a success as such in nanotechnology could counteract the alleged recruitment crises by boosting the interest for science along the same way as space research did in the 1960s and 1970s.

Nano at the Periphery: Researching Nanoparticles in Fish Vaccines

The vaccine project is located at the Faculty of Biosciences, Fisheries and Economics at the University of Tromsø—a central research institution for research in fish health issues which is of vital importance for the fish farming industry of Norway. Firmly based in fish health research this project explores nano strategies for improving salmon vaccines. While its status as a nanotechnology project turns out to be contingent, its status as a vaccine project is set, and this is why we position it at a periphery in a Norwegian nanotechnology setting. The central commitment of the project is to contribute to better salmon vaccines, and it would only endorse nano strategies in so far as this proves instrumental for this goal. While the development of the nanotechnology field is a peripheral concern for the vaccine project, this project is one of many projects that, as we will suggest, may provide arenas for critical scrutiny of the nano vision expressed at the centre.

The Salmon Vaccine Project Seen from the Centre

With a production estimated to be close to 1.000.000 tonnes in 2010, salmon is the most important export commodity in Norway next to oil, making Norway the leading producer worldwide. Fish health research has played a crucial role in the tremendous growth of salmon aquaculture, which followed from a shift from freshwater ponds to the use of sea pens in the 1970s. Farmed in open sea pens, salmon is generally vulnerable to diseases. Fish pathogens transmit well in water and high stocking densities and short distances between farms enable high transmission

rates [31]. Together with the availability of suitable and low priced feed [19], infectious diseases, including those caused by macro parasites such as sea lice [6], remain an ubiquitous problem in regions with extensive salmon aquaculture, maintaining a threat to its present state as well as a limit to its further expansion [31].

The tremendous growth of salmon farming in the first place would have been unlikely without effective vaccines. As pointed out by Aarset [1] it is no coincidence that salmon farming and fish health research have become national priority areas in the same time span; they have coevolved. In the late 1980s Norwegian aquaculture was seriously burdened by epidemic bacterial diseases, and a collapse was only prevented by an excessive use of antibiotics, which again was not environmentally sustainable. The introduction of oil-adjuvanted³ vaccines in the late 1980s was pivotal for a radical reduction of the use of antibiotics while still significantly reducing the occurrence of bacterial diseases in salmon aquaculture ([10]: 56).

The motivation for attempting to utilise nanoparticles in salmon vaccines relates to the fact that oil-adjuvanted vaccines hitherto have been ineffective against a range of intracellular pathogens (importantly viruses) and it has proved difficult to come up with strong alternative adjuvant systems [10]. Moreover, oil-adjuvanted vaccines have been found to elicit unwanted side effects in the salmon such as adhesion of internal organs in the abdomen and (although less frequently) skeletal deformations [4] and autoimmunity [16]. Vaccine producers, then, are continuously trying to apply oil adjuvants with lesser side effects.

The aim of the vaccine project in Tromsø, as stated in its project description, was to ‘develop improved formulations and optimised antigen delivery strategies’. This implied no less than the development a novel platform that not only could improve the efficiency of existing vaccines but avoid shortcomings of oil-adjuvanted platforms. The vaccines were to be mediated by nanoparticles. In other words, the enrolment of nano strategies in the field of fish vaccine research could

³ Adjuvants are substances that assist in ‘the development of vaccine efficacy by enhancing the magnitude, extending the duration and/or directing the nature of the immune response’ While adjuvants do not have specific immunogenic properties in themselves, they can make a vaccine formulation much more effective than if based on antigens alone [7].

possibly make a crucial difference for a prioritised research area in Norway. If successful, this project would significantly benefit an export industry of vital importance for Norway. Given our account of the three connected elements of the nano vision, this project appears as a core nano project potentially figuring in future lists of exemplary success stories of the enabling powers of nano. There would be good reasons for recognising the importance of the nano field if it really is the case that various forms of nanotechnologies have transformative powers of the sort. The project was funded by NANOMAT that state the following in the heading of their web page: ‘A special feature of nanotechnology is its generic character, it can affect practically all areas of society, as is described in many contexts as “the next industrial revolution”’.⁴ The vaccine project is certainly a candidate for the demonstration of such envisioned powers of the field.

Nano-Strategies in a Salmon Vaccine Context

The potentials of nano-strategies need to be worked out and verified at the laboratory floor, and it is still an open ended question whether this vaccine project might turn out to be an exemplar demonstrating valuable nano-research of the sort nano-initiatives are to stimulate.

The fish vaccine project uses particles made of a synthetic organic polymer referred to as PLGA (Poly lactic-co-glycolic acid). These particles protect antigens from premature degradation, i.e. before they can elicit an effective immune response. The PLGA particle will degrade *in vivo*, and therefore release the antigens over time. The rate of degradation of the particles can be designed by changing co-polymer composition and particle size, properties which the vaccine efficiency can be sensitive to.

The project has envisioned two strategies for nano-particle mediated vaccines. The first strategy involves the encapsulation of different ligands to the particles, which work as specific immunological ‘danger signals’. Such ligands include molecular elements that are

characteristic of virus and bacteria.⁵ Including selected ligands for specific receptors⁶ and specific antigens, PLGA nanoparticles may enable targeting of specific and desirable immunological pathways.⁷

The second strategy aims at delivering antigens directly to the internal part of cells known as the cytosol in order to, so to say, trick the cell to signal to other cells that it is infected. This is important because this pathway may elicit a particular effective immune response towards intracellular pathogens such as viruses. An immune response of this type can normally only be achieved by infecting cells, e.g. by live attenuated (weakened) virus strains. The drawback of using attenuated virus strains, however, is that they may mutate and hence revert into virulent forms, a drawback which can be avoided with vaccines composed of PLGA particles in combination with inactivated virus or subunit antigens.

These two strategies form the focus of the nano identity of the project when scrutinised at the laboratory level. The particles consist of physically assembled nano-constituents. In addition, in the second case, the nanosize of the PLGA particles may enable them to pass, or be transported, into the cytosol and elicit a particular response.

Research in the Periphery of Nano

The researchers of the vaccine project, are first of all interested in developing better vaccines, regardless of whether the project would fall within the boundaries of nano or not. Seen from the laboratory floor, the nano identity of the project does not appear essential. With regards to the research done in the fish vaccine project these discussions of the nano identity of the project is hardly interesting internally to the group. The researchers would have pursued this strategy regardless of it being enrolled as nano or not, provided it was funded. They simply believed in this strategy which happened to be a nano strategy found worthy of receiving grants from a prestigious strategic funding program for nano. This is one of the objectives of such programs; to stimulate certain priority areas.

⁴ See the Research Council of Norway’s web page for the NANOMAT program. (<http://www.forskningsradet.no/servlet/Satellite?c=Page&cid=1226993562769&p=1226993562769&pagename=nanomat%2FHovedsidemal> Downloaded December 2010).

⁵ Such ligands include lipopolysaccharides, peptidoglycan, and DNA fragments rich in CG (CpG motifs).

⁶ I.e. so-called Toll-like receptors.

⁷ E.g. a so-called CTL response or a Th-1 biased response.

The fish vaccine project has its identity and commitments in fish immunology/vaccinology. The project description refers to these fields, and the conferences and journals of these fields are considered as the relevant communication channels. The project was not a result of a deliberate turn to nano, like in an ambition to establish generic nano research at its host institution.

The way one of the vaccine researchers obtained a nano-derived nick name (as in ‘Nano-Nikolai’, illustrates how nano was received as something rather exotic in the fish health research environment. Being a rarity, as well as being enrolled into a nano ELSA project, strengthened the project’s nano identity, and nano issues were reflected upon within the research group and among their peers. One important issue concerned the question of if and how the risk literature on nanoparticles should have any effect on the development of the project. We have not, however, been able to trace how any of this nano awareness provided reasons for modifications of the pursued lines of research.

The researchers had to reach outside their customary research domain in order to learn how to design PLGA particles with specific desired properties. For this purpose, their project involved sending a PhD student to a pharmaceutical laboratory in London in order to learn to master the fabrication of these particles. One might call this an integration of a nanotechnological skill, but one might as well question what specific difference the prefix nano would do, as this could be seen as extension of the skill of making micro PLGA particles. This type of exchange of skill is quite common part of any scientific activity [24]. While being funded as a nano project contributed to the scientific identity of this project, the utilisation of nanoparticles does not appear to make a distinctive difference for the projects identity as a fish immunology/vaccine project.

The commitment of a research group like this is to work out a doable and verifiable experimental system in which salmon vaccines can be tested and perhaps improved. Nano strategies are mobilised in so far they do so. In this particular case the dynamics of experimentation might even imply that the researchers work themselves out of the domain of nano altogether. The projects strategy of using nanoparticles as vaccine delivery vehicles seemed to be optimal when proteins and adjuvants were to be co-encapsulated. Further, particles larger than 5–10 μm , due their size, remain at the site of injection, releasing the antigens to neighbouring cells. In contrast, nanoparticles appear to be

readily taken up by cells and can thus be transported to sites distant from where they were injected, possibly leading to accumulating of particles in lymphoid organs or that they are broken down and excreted. As antigen retention after injection is a key characteristic for a vaccine, it appeared interesting to explore immunological differences of administering nano- or microparticles and to look into potential synergistic effects of these in respect to vaccine potency. Thus the project now partly aims at comparing nano- and micro sized particles as potential vaccine delivery systems.

In part, these developments seem to imply a drift away from the nano domain. Rather than sticking to explorations of designs within the nanoscale, the project has shifted to compare efficiencies of micro and sub-micro designs and their combinations. The project appears to drift towards strategies that have been pursued with microscale particles in other contexts, which raises the question of the uniqueness of the strategy, compared to previous ones. If this would imply that the ‘nanoness’ of the project would be questioned—that the researchers would, so to speak, have researched their way out of nano, this would not worry the researchers as such. The primary objective here is to make better vaccines, not to stick to deploying a strategy recognisable as nanotechnology. However, as the researchers point out, this shift towards larger particles may be reversed later if the new concept fails—as there are numerous parameters within the manufacturing process of nano vaccines that can be manipulated.

If researchers knew what results would turn out from their experiments, their activity would hardly qualify as research in the first place. Success here is potentially a verification of a nano vision as seen from the centre. Things look different from the perspective of a project at the periphery. While nano strategies may be explored here, the project’s scientific identity, objectives and commitment are marked by the field of vaccinology that in turn constitutes the metric of the nano strategies.

Centre, Periphery and Exemplars

This article has contrasted two arenas of nano research activities, situated along a centre-periphery axis. We situate the salmon fish vaccine project in the periphery of nano because it could as well be described without the nano label, as a project

continuing research strategies of fish immunology or vaccinology. We situate the NTNU NanoLab initiative, on the other hand, at the centre of nano as it represents an initiative that explicitly aims at promoting the field of nano.

Seen from the perspective of the centre, we suggest, a project like the fish vaccine project explores the potentials of engineering ‘at the bottom’. At stake in this case is the question of what revolutionary difference nano strategies can do for the field of fish vaccinology. The vision of the centre, as we describe it, consists of three connected elements. The overall potentials of nanoscale sensitive technologies may be released through cross-disciplinary efforts and manifested in socio-economic benefits. This vision call for deliberate reorganisation and investments in social and material structures of the sort NTNU NanoLab seeks to establish.

The fish vaccine project has what it takes to even become a model exemplar of what is to be achieved by such initiatives. Imagine that crucial problems of fish health were improved for the whole aquaculture industry due to deployment of nano strategies in fish vaccines. Given a successful implementation in fish farming industry, the extraordinary potentials of nano would have been demonstrated. The nano vision, one may say, would have come true here. The vaccine project could have filled the role of such an exemplar regardless of whether or not the project arose out of nano strategic initiatives. As an exemplar, it could exemplify what initiatives like NTNU NanoLab aim at promoting and facilitating.

Bringing the field into life is not only a matter of creating novel experimental facilities, like the clean room facilities developed at NTNU. Understanding nano as a paradigmatic arena of Mode-2 trends, the standard story of nano comprises a vision for novel modes of knowledge production. We understand NTNU NanoLab as one arena for exploring potentials of more context driven means of knowledge production of the sort we have not yet seen fully realised.

Meanwhile, projects in the periphery, like the vaccine case, may provide important arenas for discussing and validating standard visions of nano, regardless of their success or failure. The critical potential of projects at the periphery lies in the commitment to an experimental system that, for instance, evolves around the challenge of improving fish vaccines. Rather than understanding the vaccine case as a project mimicking the research strategies

and visions of the centre, the roles of centre and periphery may be seen as inversed as it is in projects like this that the vision, and accompanying prescribed reorganisation of research, currently can be examined. The trends towards new modes of organising knowledge production are simultaneously scrutinised and evaluated in these arenas for nano activities we describe as being in the periphery of nano.

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References

1. Aarset B (1997) From consensus to specialization: institutional aspects of Norwegian aquaculture research. *Rev Fish Sci* 5:303–322
2. Baird D, Vogt T (2004) Societal and ethical interaction with nanotechnology (SEIN)—an introduction. *Nanotechnol Law Bus* 1:391
3. Bawa R, Bawa SR, Maebius SB, Flynn T, Wei C (2005) Protecting new ideas and inventions in nanomedicine with patents. *Nanomed Nanotechnol Biol Med* 1:150–158
4. Berg A, Bergh Ø, Fjellidal PG, Hansen T, Juell JE, Nerland A (2006) Animal welfare and fish vaccination—effects and side-effects (in Norwegian). In *Fisken og Havet*. Institute of Marine Research, Bergen
5. Berube D (2006) Nano-hype: the truth behind the nanotechnology buzz. Prometheus Books, New York
6. Costello MJ (2009) The global economic cost of sea lice to the salmonid farming industry. *J Fish Dis* 32:115–118
7. Evensen Ø, Brudeseth B, Mutoloki S (2005) The Vaccine Formulation and its Role in Inflammatory Processes in Fish—effects and adverse effects. In: Midtlyng P (ed) *Progress in fish vaccinology*. Basel, Karger
8. Gibbons M, Limoges C, Nowotny H, Schwartzman S, Scott P, Trow M (1994) *The new production of knowledge: the dynamics of science and research in contemporary societies*. Sage, London
9. Hacking I (1992) *The Self-Vindication of the Laboratory Sciences*. In: Pickering A (ed) *Science as practice and culture*. Chicago University Press, Chicago
10. Håstein T, Gudding R, Evensen Ø (2005) Bacterial vaccines for fish—an update of the current situation worldwide. In: Midtlyng P (ed) *Progress in fish vaccinology*. Basel, Karger, pp 55–74

11. Huang Z, Chen H, Yip A, Ng G, Guo F, Chen Z, Roco MC (2003) Longitudinal patent analysis for nanoscale science and engineering: country, institution and technology field. *J Nanopart Res* 5:333–363
12. Hwang K (2008) International collaboration in multilayered center-periphery in the globalization of science and technology. *Sci Technol Hum Values* 33:101–133
13. Jotterand F (2006) The politicization of science and technology: its implications for nanotechnology. *J Law Med Ethics* 34:658–666
14. Klaessig F (2010) Nanotechnology: paradigm or bubble. Paper presented at the Second Annual Conference of the Society for the Study of Nanoscience and Emerging Technologies, Darmstadt.
15. Knorr-Cetina K (1999) *Epistemic cultures: how the sciences make knowledge*. MIT Press, Cambridge
16. Koppang EO, Bjerkas I, Haugarvoll E, Chan EKL, Szabo NJ, Ono N, Akikusa B, Jirillo E, Poppe TT, Sveier H, Torud B, Satoh M (2008) Vaccination-induced systemic autoimmunity in farmed salmon. *J Immunol* 181:4807–4814
17. Li X, Chen H, Dang Y, Lin Y, Larson CA, Roco MC (2008) A longitudinal analysis of nanotechnology literature: 1976–2004. *J Nanopart Res* 10:3–22
18. NanoLab (2008) NTNU Nanolab—annual report 2008. NTNU, Trondheim
19. Naylor RL, Hardy RW, Bureau DP, Chiu A, Elliott M, Farrell AP, Forster I, Gatlin DM, Goldburg R, Hua K, Nichols PD (2009) Feeding aquaculture in an era of finite resources. *Proc Natl Acad Sci* 106:15103–15110
20. Nordmann, A (2004). *Converging Technologies—Shaping the Future of European Societies*. Report to the European Commission’s Directorate General for Research. Retrieved December 15, 2010, from <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.133.2322&rep=rep1&type=pdf>.
21. Nowotny H, Scott P, Gibbons M (2001) *Re-thinking science: knowledge and the public in an age of uncertainty*. Polity press, Cambridge
22. NTNU (2003) *Nanotechnology at NTNU*. The Norwegian University of Science and Technology, Trondheim
23. NTNU (2008) *Evaluation of the engineering education at NTNU*. NTNU, Trondheim
24. Porter AL, Youtie J (2009) How interdisciplinary is nanotechnology? *J Nanopart Res* 2009:1023–1041
25. Rheinberger H-J (1997) *Toward a history of epistemic things: synthesizing proteins in the test tube*. Stanford University Press, Stanford
26. Roco MC, Bainbridge WS (eds) (2001) *Societal implications of nanoscience and nanotechnology—NSET Workshop Report*. National Science Foundation
27. Schott T (1998) Ties between center and periphery in the scientific world-system: accumulation of rewards, dominance and self-reliance in the center. *J World-Syst Res* 4:112–144
28. Schummer J (2007) The global institutionalization of nanotechnology research: a bibliometric approach to the assessment of science policy. *Scientometrics* 70:669–692
29. Shew A (2008) Nanotech’s history: an interesting, interdisciplinary, ideological split. *Bull Sci Technol Soc* 28:390
30. Shew A, Baird D (2004) Probing the history of scanning tunneling microscopy. In: Baird A, Nordmann A (eds) *Discovering the nanoscale*. Ios Press, Amsterdam, pp 145–156
31. Sommerset I, Krossøy B, Frost P (2005) Vaccines for fish in aquaculture. *Vaccines* 4:89–101
32. Traweek S (1992) Border crossings: narrative strategies in science studies and among physicists in Tsukuba Science City, Japan. In: Pickering A (ed) *Science as practice and culture*. The University of Chicago Press, Chicago
33. Vogt T, Baird D, Robinson C (2007) Opportunities in the ‘post-academic’ world. *Nat Nanotechnol* 2:329–332
34. Wullweber J (2008) Nanotechnology—an empty signifier à venir? A delineation of a techno-socio-economical innovation strategy. *Sci Technol Innov Stud* 4:27–45
35. Ziman J (2002) *Real science: what it is and what it means*. Cambridge University Press, Cambridge