N E X T
TO NOTHING

A STUDY OF NANOSCIENTISTS AND THEIR COSMOLOGY
AT A SWEDISH RESEARCH LABORATORY

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Illustrations

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1. Introduction

Between April 2003 and June 2004 I passed almost daily through the entrance to MC2, *the Department of Microtechnology and Nanoscience*, at Chalmers University of Technology in Gothenburg, Sweden, to conduct anthropological fieldwork. A poster placed at the facility entrance declared "We offer next to nothing." The poster being a pun, imply that funding agencies are spending a lot of money on almost nothing, still this almost nothing is hoped to revolutionize our society. The "next to nothing" of the poster is the realm of atoms and molecules, existing on the nanometer level, one nanometer (nm), being one-billionth of a meter. The researchers who explore this level are referred to as nanoscientists and presently funding agencies and nano-proponents put much hope into their research. It is hoped that within a short time they will create the means to produce cheaper energy and faster computers and that, given more time, they will create conditions for longer lives and the eradication of diseases and pollution. In the minds of many laypersons nanoscience presents prospects for continued industrial development without the collapse of nature. Thus, there are many reasons for policy-makers and politicians to promote the new technology hoping that the nanoscientists' offer of next to nothing will positively influence social and economical development. The "next to nothing" offered to us by nanoscientists is consequently more than merely an access to the nanometer level. During the fieldwork I also realized that it was possible to interpret the poster socially in the sense that the nanoscientific community offers insights into a community which is constructed socially and culturally by a self-image aspiring to be "next to nothing." The researchers form a community that is based on an ideal of individuality, the minimal level of sociality, and where many collective traits that commonly are associated with both the identification of the group and the forming of its outlook on the world are considered to be irrelevant for their practice as researchers.

A year after my fieldwork was completed I was invited to a dissertation party at MC2. One of my principal interlocutors presented his thesis. He politely sent me a copy of his dissertation fully aware that I could not understand the physical formulas. Nanoscience is ideally open to all but in reality it is a closed sphere of knowledge. The researchers at MC2 have undertaken years of university training to become physicists or physical/electrical engineers and thus understand the fundamentals of physics as well as the particular discursive expressions that have emerged in nanoscience. Although we might have taken physics at school we rarely share the nanoscientists' depth of knowledge or of technical skills; giving rise to the laypersons' limited knowledge of scientific understanding of the world. The extent of misinterpretation became clear to me when I started to compare how nanoscience was understood among the general public and how it was understood among the researchers at MC2. Nanoscience outside the walls of science consists to a high degree of utopic and dystopic visions with world altering prospects while inside the walls it consists mostly of mundane projects such as working with coatings, etchings and nanotubes.

At the dissertation party I was reunited with some of the researchers I got to know during my fieldwork. At the table where I sat during dinner there were people from Romania and Sweden sitting next to people from Pakistan, Sudan and Malaysia. We were served Thai food, desserts from Sudan and Swedish muffins with the coffee, while being entertained by song and music from Bangladesh. Some of those whom I had got to know as students had now finished their theses and were ready to move on to other universities or commercial enterprises of which only a few were located in Sweden. The nanoscientific community is transnational, like the dissertation party, with scientists from all over the world coming and going; but it is a closed transnational community limited in space and social interaction as it is bound to those universities and large corporations that are able to facilitate this expensive form of research. Despite the national diversity of the researchers the majority of them come from similar middle class backgrounds which prioritize higher education, have the financial means to attend university but need a job to support themselves. This shared social background of the global middle class gives the nanoresearchers a sense of familiarity when acting inside their scientific community.

Apart from the researchers' common social background, the community of nanoscientists is united by a shared understanding of the nanoworld, which is my main focus for the dissertation. More specifically I explore *cosmological notions of the nanoscientists at MC2 and how such notions are created, maintained and strengthened through their conceptualization of nature and self as founded in the everyday practice of being a scientist.* The term "cosmology" has its root in the Greek word "kosmos," meaning the world or universe as an ordered system (Barnard & Spencer 1996: 129). The concept of cosmology is used by physicists for the study of the universe and the laws which govern it, and students of physics take courses such as "Theory of relativity and cosmology" and "Gravitation and cosmology." The cosmological notions found among the researchers at MC2 are part of a larger natural scientific cosmology found in academic disciplines such as biology, chemistry and physics, in which the universe is formed by atoms and molecules that follow natural laws. This materialistic and mechanistic notion of the universe leads to an ideal of objectivity that places matter in the centre for research and excludes or minimizes non-material parameters. Life, for example, is seen as emanating from the atomic world and humans from a "materialistic stance" are viewed as lumps of coal.

From the perspective of nanoscientists nature may, accordingly, be defined as "… everything of purely material character that we can, or can conceivably, observe and measure" (Rosen 1995: 169). In short, nature means matter that is formed by atoms and molecules and the natural laws they abide by. Nature, being inanimate, is not to be seen however, as something passive upon which humans act, as the nanoworld is full of momentum for the researchers to control and interact with. Among nanoscientists the key to good science is verification through systematic experimentation on nature. The knowledge that nanoscientists obtain from experiments and theoretical deduction is in its ideal form perceived of as objective and accordingly it is non-cultural.

This materialistic cosmology is not only an intellectual construction since it also influences the everyday activities of the researchers as part of a dynamic lifeworld. Through education nanoscientists come to share a common cosmology on how the universe is constructed which they subsequently become professional creators and upholders of. The use of scientific books creates conformity and common interests among the students and as a researcher at MC2 noted "a tendency to use well defined mathematical terms in ordinary life is developed." As an example of such expressions the researcher told me that he and his friends, during their undergraduate years, had talked about "persons who were oscillating to converge later" for people who change opinions easily. In physics "to oscillate" means to "pendulate" and to "converge" is a geometrical concept that describes how lines move together towards the same point. He concluded that many physicists have an absolute view of knowledge, meaning that it is possible to arrange reality into boxes which can be described by well defined terminology. This terminological structure creates problems, however, when physicists use such well defined terms in conversations with non-physicists. The transformation from layperson to expert thus includes changes of both language and modes of thinking that make communication with laypersons harder, constructing a wall between those who are initiated and those who are not.

Among nanoscientists there is a common conceptualization of an essentialist and non-cultural science, "a culture of no culture" (Traweek 1988). From the perspective of nanoscientists, culture is something that principally exists outside of science, and consequently, it is largely absent inside of science. Cultured conceptions, being phenomena that are subjective, have for the researchers nothing to do with the ideal objective science. This implies that nanoscience ideally should not be affected by external factors such as politics, ethics or commercial interests.

The anthropological study of scientists

This study is part of a grander tradition of conducting anthropological fieldwork among scientists. My study is an ethnography which tries to understand how the researchers experience their science at work and consequently the private lives of the researchers' have generally not been touched in this ethnography.

Conducting anthropological fieldwork among scientists was first done in the late 1970s and early 1980s. Among early pioneers were Bruno Latour and Steve Woolgar (1986) who wrote about Latour's fieldwork in a laboratory at the Salk Institute. Reflecting on this new kind of field setting they observed:

> Whereas we now have fairly detailed knowledge of the myths and circumcision rituals of exotic tribes, we remain relatively ignorant of the details of equivalent activity among tribes of scientists, whose work is commonly heralded as having startling or, at least, extremely significant effects on our civilization (Latour & Woolgar 1986: 17).

By the 1980s disciplines such as history, philosophy and sociology had come to dominate social studies of science, often referred to as "science and technology studies." An impact of this meant that concepts such as "fieldwork" and "ethnography" in science and technology studies, were defined by sociologists and philosophers. The concept of ethnography in science and technology studies has therefore been used in a much broader sense than within anthropology, covering all kinds of fieldwork-based methods, even though there are anthropologists active in the field of science and technology studies (Hess 1997: 134).

Of the anthropological studies conducted among scientists there are principally three ethnographies that have influenced my thesis. One of the studies is Sharon Traweek's (1988) comparative study of high-energy physicists in Japan and the USA. Traweek has become renowned for describing the culture of physicists as the "culture of no culture." By this concept she was describing a culture of an alleged extreme objectivity in which the scientists perceived themselves as free from preconceptions when conducting research. It is a culture that, assumedly, does not pay any explicit attention to issues such as nationality, gender and emotions and it is therefore supposed to provide perceivably eternal truths about the objective world (Traweek 1988: 162). The notion of extreme objectivity inherent in the "culture of no culture" is also found among the researchers at MC2. In my thesis I elaborate on Traweek's concept by arguing that the "culture of no culture" among nanoscientists is based on individualism. What is valued in the nanoscientific community are personal skills, and shared attributes such as class, ethnicity and gender are of no importance for doing research. Paradoxically, these personal skills are ideally to be shared with the rest of the community, as experiments are to be verified and repeatable by fellow researchers, not tying results to a single individual.

Also Diana Forsyth's (2001) ethnography on researchers of Artificial Intelligence depicts a community that sees itself as lacking culture. The scientists in her study argue that their discipline is purely technical, suggesting that they therefore can disregard socio-cultural aspects when programming. As can be expected their approach to science is universalistic. Forsyth describes how this universalistic notion creates two kinds of knowledge; a local cultural knowledge and a global commonsense knowledge. In my thesis I elaborate on Forsyth's dichotomy between the global and the local as nanoscientists seem to separate between science which is perceived of as objective and global and culture which is perceived of as subjective and local.

Most anthropologists who have conducted fieldwork among scientists have shown little or no interest in the social stratification of class. One exception is Hugh Gusterson (1996) whose study of nuclear weapon physicists describes the struggle between groups of scientists split by a new kind of subdivision of the middle class; between technical and humanist. In a broad sense the technicians are for the construction of nuclear weapons in opposition to humanists who are against it. The antagonism that exists between the two groups is generated by the university system which is overproducing humanists relative to the job opportunities, thus creating a group with high cultural capital but with low financial capital, in comparison to the technicians who have both social influence and high income. Among the technically oriented nanoscientists in this study there are no clear factions of opposition similar to the antagonists of nuclear weapon physicists and most of the nanoscientists I talked to interacted only minimally with the public and rarely participated in public debates on their science.

Apart from the authors above I have also found inspiration in the work of Pierre Bourdieu (1979, 1990) and Tim Ingold (1993, 2000). Neither of them has conducted extensive fieldwork among scientists but their work touches upon subjects of importance for this study.

Pierre Bourdieu (1996) has written about scientists but this work I have not found useful due to its strong emphasis on Parisian French academia. Instead I have found Bourdieu's (1979) earlier work on social class of interest to understand the lifestyle of the people at MC2. Bourdieu argues that different labor categories create different lifestyles, manners and taste and he emphasizes the importance of upbringing and education for these distinctions. Social class, moreover, is produced not only by mental processes such as upbringing, education and work but also manifests itself in the physical body through food choices, physical exercise etc. The nanoscientists in this study create class-distinctive norms of taste through, for example, a liking for mathematics, finding aesthetic values in nature and a dress code of not sticking out in a crowd.

Of importance for this study is Ingold's (2000) notion that humans actively live in and form their surroundings, stressing that landscapes are practiced and actively formed through social interaction. This is clearly seen among the researchers when conducting research in the human controlled laboratory landscape called "the cleanroom." It is not only the scientists who form nature as the nanolevel environment also demands that humans wear protective gear to be able to manipulate single atoms and molecules. Human-nature relationship is consequently a two-way communication. According to Ingold (2000) human activities are placed in landscapes and skills are defined as trained and experienced capacities situated in the environment. Even though I use the term "skills" in a more restricted sense than Ingold, whose definition allows animals to possess them, it is important to stress that skills among scientists are not only developed through social interaction with colleagues but also through trial and error, i.e. social interaction with nature.

Doing ethnographic fieldwork among scientists

Once when I discussed my work with two researchers from MC2 I tried to describe anthropological fieldwork; how in the classical sense it is synonymous with participatory observation, including informal interviews and living with informants, and how the outcome of this experience is the ethnography. This could also include learning a foreign language and living abroad for a year or two. Suddenly one of them jokingly said "we are your specimens, you are experimenting on us," and in translating the language of nanoscience to the language of anthropology, he was correct. In short, specimen/interlocutor is the matter you study while experiment/fieldwork is the method of acquiring information from the specimen/interlocutor. The analogy between studying inanimate particles and scientists is, however, not to be drawn too far. A difference is that the information for this thesis is created through the social interaction between me as the observer and the scientists as the object of study, whereas the researchers at MC2 do not consider themselves to interact socially with their specimens. Another difference is the verification criteria. It is not the aim of this thesis to discover what is true or not in nanoscience, but what people believe to be true and false, that is, how they construct their world. It is important to differentiate between the product of science, being the domain of the scientists, and the scientific activity, being the object of this study (Hacking 1999: 67).

By focusing on the social worlds of scientists and not on the actual science, the social scientists' description of natural science is therefore distorted from the natural scientists' perspective. According to Latour and Woolgar (1986: 19) this distortion raises two concerns. Firstly, the ethnography produced can lead to a disinterest among natural scientists and others as it can be perceived as dull since it does not describe the scientific results but the scientists and their doings. Secondly, by not focusing on the actual science the researchers studied may become suspicious of the social scientists that centre on things that the researchers conceive of as irrelevant, e.g. conflicts, anthropomorphic language practices, science as a literary activity etc. The researchers in this study, for example, conceive of themselves as non-cultural beings while my study focuses on the cultural aspects of being a scientist. Thus, from their perspective, this thesis may lack relevance for them as researchers and, moreover, it may seem to contrast with central aspects of their cosmology.

However, I would argue that by not focusing on the scientific results the researchers are more relaxed as they do not perceive the anthropologist as a threat. Talking to the anthropologist becomes something outside the ordinary routine, as a researcher told his colleagues over lunch "it is fun to take Mikael along, it is like being accompanied by a child, he asks a lot of questions and I have to show him everything."

Conducting fieldwork among nanoscientists also raises the question of *studying up*, i.e. studying elites. The nanoscientists at MC2 pass through university training to form part of a global scientific elite. From the perspective of national states, the global elite of natural scientists is the backbone for future prosperity. In her seminal article on studying up Laura Nader (1969) argues that there are many obstacles to such an undertaking. One problem is to get access to influential people as they do not necessarily want to be studied. Fortunately, my access to researchers at MC2 did not encounter such obstacles. Since anthropology is mostly unknown among the nanoscientists partaking in this study, it is so far off from what they normally do that my research becomes interesting. However, as many of the researchers at MC2 work over 60 hours a week it was sometimes hard to arrange interviews. The method of participatory observation was therefore of great advantage in this environment; hanging around, talking to people during coffee breaks, lunches and during their spare time made up for the researchers' lack of time for formal interviews. I also had full access to the department, including the entire laboratory, which meant I could follow the researchers when conducting science.

Another problem mentioned by Nader is the attitude of the informants. Since the powerful rarely want to be studied they may not want to have an anthropologist hanging around, an experience that e.g. Paul Rabinow (1999) had when conducting fieldwork among French scientists. In the case of studying researchers at MC2 I have not met with any negative attitudes, but the gaining of trust is, of course, a process that takes time. I have known some of the researchers since 1999 and by using their networks I got access to other researchers by recommendation. Moreover, over time, in this case over a year, a certain trust is likely to develop unless communication breaks down completely. Another advantage of participatory observation is that by being at the facility the nanoscientists also get a chance to know the anthropologist. Initially I taped interviews but soon discovered the disadvantages of this approach. Tape recording means freezing a point a view and many of the replies I got were polite and politically correct. I also noted that a number of interviewees felt uncomfortable with the recorder. I soon shifted to the less conspicuous pen and paper, thinking about the irony of using these instead of a tape recorder in a community working with cutting edge technology.

A third issue with studying up mentioned by Nader is that participatory observation works best in social settings with defined spatial boundaries such as villages or among geographically defined peoples. Elites, in contrast, may move globally between localities where anthropologists are not always allowed, such as board meetings, private yachts, luxury hotels etc. thus making traditional fieldwork hard if not impossible in these settings. Participatory observation in laboratory settings, however, has proven to work well. The laboratory environment is a defined spatial area with a set group of people, in many respects similar to more conventional fieldwork settings. Documents, telephones and computer files are tools added to the classical method of participatory observation. The fieldwork conducted at MC2, engaging approximately 200 scientists, also included reading official documents and web-pages. Since the researchers move globally and have many international contacts, quite a few of them have elaborate home pages with *curriculum vitae's* and information about themselves, both professional and private. These electronic sites also proved a fertile field to roam. The use of e-mail proved invaluable for making appointments, getting short comments on specific subjects and obtaining follow-up questions to interviews.

An ethical problem that arose during the fieldwork is that many of the researchers, not being familiar with anthropological fieldwork, were most probably not fully aware that what they said at coffee breaks, small talk, laboratory visits etc. may end up as quotes in this dissertation. I have tried to inform all of the participants to the best of my ability, but the process of participatory observation also means to become part of normal life striving for the subjects to "forget" that you are there to study them. Maybe a bit of dishonesty is imbedded in the process of conducting anthropological fieldwork as it includes not always telling the subjects what you are really after since this may influence their answers. A few researchers gave me permission to use their real names but I have chosen not to include any names. When working with a limited number of individuals, in this case approximately 200 researchers, they are identifiable by several different characteristics, such as the work they do or their nationality. There is, for example, one group working with photons and there are two researchers at MC2 coming from Sudan. By mentioning someone working with photons or by describing someone as coming from Sudan it becomes easy for the initiated to identify the source of information. I have therefore chosen not to include any personal descriptions that might make individuals identifiable.

Finally, I would like to focus on an issue that is often addressed when writing ethnography; what to do with the native's point of view in relation to analytical interpretations not shared by those studied. A good example of this analytical alienation is Latour and Woolgar's (1986: 48-49) characterization of scientists as "compulsive and almost manic writers." This became the foundation of their analysis of the laboratory as a paper producing facility. When scientists see machines that produce scientific results, Latour and Woolgar see inscription devices that transform material substances into diagrams that are to be used in documents. The scientists resented the idea that they participated in a literary activity since they were scientists and not writers. In a similar manner, I have alienated myself analytically from the nanoscientists. The jargon the researchers use to describe their daily life sometimes make direct quotations problematic because they are technical and what was said needs quite a lot of explanation. For increased readability I therefore decided to focus on the content of what was said and not on direct quotations, making me the transitory spokesperson. I have also chosen to use analytical terms like "culture," "cosmology," "technoscape" etc. when describing nanoscientists' views, that may seem both alien and alienating to them.

Central concepts

In this examination of the cosmological notions of nanoscientists at MC2 there are some key concepts that are used as foci for the study. The concepts—intra- and extramurality, individualism, technoscape, and skills—differ in many respects, particularly as to their degree of analytical abstraction. However, what they all have in common is that they touch upon central dimensions of both the social life and identity of the nanoscientists upon whom this study focuses.

The "extra-" and "intramural" pair of concepts are interrelated. The *extramural*, outside the walls, stands in contrast to *intramural*, inside the walls. I use these terms in a literal sense representing the researchers' conceptualization of the scientific world as ideally separated and closed from the everyday non-scientific world. Intramural science is, from the researchers' perspective, disembedded from the surrounding society which, accordingly, is seen to be of little concern for their research. By disembedding intramural science from the extramurally surrounding society, science is presented as universalistic and accordingly conceived of as being characterized by objectivity. Actually, the nanoscientific community is, in principle, a global community in which people from all over the world largely interact within closed intramural social spaces, i.e. the research facility, at the expense of developing extramural social contacts. The divide between intramural/extramural space also applied to me as an anthropologist. During the stay I socialized partly as an insider while my knowledge skills were those of an outsider, leaving no doubt that I was an outsider roaming around in the closed intramural social space of nanoscientists at MC2.

The perceived social disembeddedness experienced by the scientists in this study seems to be a feature that these nanoscientists share with other modern experts (Giddens 1990). Scientific facts, from the researchers' point of view, emerge without an active cultural human agency (Traweek 1988: 161, Forsyth 2001: 2). By dealing with "facts of nature," the researchers partake in a universal quest for discovering objective truths; a quest that among its advocates is seen as being conducted without the influence of culture. By trusting machine affirmation of experiments and mistrusting individual subjectivity they deny human agency a place in the making of those objective truths, which are, from the researchers' perspective, constructed without humans.

As mentioned earlier the people in the nanoscientific community emphasize *individualism*. "Individualism" in this sense has to be distinguished from "individuality;" the first being a historical and cultural conceptualization of personhood that largely is associated with Western society while the latter usually refers to the universal nature of human existence according to which it is individuals who possess agency (Rapport & Overing 2000: 178). The starting point for individualism as a historical concept has been located at different time periods with a Western focal point (e.g. Beck & Beck-Gernsheim 2002, Lukes 1971, Sahlins 1996). Louis Dumont (1986: 60) also points out that individualism is often used as a characteristic for "modern societies" in contrast to more "traditional societies," where forms of collectivism are supposed to be more crucial.

According to Steven Lukes (1971: 51) individualism takes a person out of society and makes him or her into the creator of his/her own surroundings and destiny. Ulrich Beck and Elisabeth Beck-Gernsheim (2002: 5) even go as far as to describe the coming of a *self-culture* in which gender, marriage, religion, social ties etc. are all to be decided by the individual. This self-culture emerges as the distinction between the working and the middle class disappears (Beck & Beck-Gernsheim 2002: 42). The predicted dissolution of social classes stands in opposition to the notion that individualism is a middle class idea (Lukes 1971: 84). According to Lukes, individualism grew from liberal and utilitarian ideas in which people should compete and pursue their own interests; ideas advocated by the then growing middle class. I would suggest that the attributes ascribed to individualism, the ability to make choices to form one's own career and social life etc, are attributes emphasized by a global middle class. As Bourdieu (1979) points out, individual choices perceived to be available are guided by our social surroundings.

Among the researchers at MC2 individualism is taken to its extreme as each researcher is ideally judged by his or her individual competence and not by collectively shared characteristics. By reducing the importance of shared attributes to a minimum the nanoscientists are therefore seen to constitute a collective of similar peers that culturally are characterized by "next to nothing." As a paradox, by reducing the importance of shared attributes the researchers also reduce the importance of individuality as each person's notion of the self is a product of shared traits such as nationality, gender, social class etc. This means that the de-collectivization also leads to a de-individualization of the researchers.

Another aspect of importance for this thesis is the researchers' interaction with their environment. Ingold (2000) combines the three concepts of livelihood, dwelling and skills in the formation of landscapes. He argues for a dwelling perspective in which humans actively live in and form their surroundings, seeing human-nature relations as ecological. Ingold (2000: 195) uses the term *taskscape* to describe the activities of normal life that takes place in a specific environment. While focusing on everyday life in modern industrial societies Michel de Certeau (1984) stresses in a similar manner that landscapes are practiced; i.e. they are actively formed by social interaction. For de Certeau everyday practice, such as going to work daily following the same route, becomes a repetitive and unconscious act for the individual. In the same sense work at MC2 becomes routine for the researchers and moving around in the cleanroom laboratory with its restrictions on bodily actions, becomes a normality that is unreflected upon.

In this thesis the term *technoscape* describes the human made landscape of technology. The term "technoscape" has also been used to describe transnational flows of technologies (Appadurai 1990) but I use the term to portray a specific landscape which differs from natural landscapes in that it is constructed and controlled by humans. To be able to manipulate and visualize the nanometer level of reality, nanoscientists surround themselves with all kinds of technology, from office spaces and computers to ovens and lithographs. Technology becomes the mediator between humans and the nanoworld, a world beyond immediate human experience. By working in this technoscape, doing everyday activities, the researchers at MC2 construct, preserve and reinforce their scientific cosmology. MC2 becomes a landscape that is practiced and unreflected for those working in it, as argued by de Certeau (1984). The technoscape described here belongs to the intramural sphere; it is a closed space in which science is conducted separately from the surrounding environment. It is also a landscape controlled by humans for the purpose of interacting with nature in order to transform it into human constructed artifacts. The most extreme part of the technoscape at MC2 is the cleanroom laboratory which is where the researchers interact with the nano-level world; a world which must be protected from both humans and outside influences due to the risk of pollution.

Research in the nanoscientific technoscape at MC2 has an experimental focus making *skills* for handling machines essential. Ingold (2000: 5) uses the term skill in a wide sense as an attribute not only of humans but also of animals, since skills are trained and experienced capacities of action/perception situated in the environment. In this thesis I use the term "skill" in a more limited sense meaning the acquired ability used in a particular environment. Skills are in this context abilities that are not shared by all, such as, for instance, doing advanced calculations, programming computers and handling lithographs. In short, the skills of relevance here are those special abilities that make researchers into nanoscientists. Many of the skills are useful only intramurally in a technoscape designed to manipulate the nanoworld. Skills are acquired through learning and observation but also through trial and error by interacting with nature. Nanoscientists distinguish between two different kinds of skill; one kind is held by theorists and the other by the experimentalists. Theorists use skills such as mathematics and the handling of computer programs to create models of the nanoworld while experimentalists use practical skills such as machine handling to domesticate the nanoworld. The border between the theorists and experimentalists gets a bit blurred nowadays when experiments can be done by computers. However, at MC2 approximately eighty percent of the researchers consider themselves to be experimentalists.

The use of theoretical and practical skills in the nanoscientific technoscape is such an integrated part of everyday practice that it becomes oblivious to the users themselves. One such understanding is that the everyday practice of handling machines is not emphasized when conducting research. Skills are not only connected to the ability to handle machines but also to the ability to move around in the technoscape without causing experiments to fail due to reckless behavior. Skills are thus also about discipline as they are used to limit inappropriate behavior and to create a routine of appropriate behavior. With time, skills such as respecting behavior codes in the cleanroom laboratory and looking through a microscope etc, become so entangled in the everyday practice of being a researcher that they are not reflected upon.

Outline of the thesis

Chapter two, *Visions of nanoscience,* describes the discrepancy between nanoscience inside and outside the scientific community. To the general public nanoscience is often described with either utopic or dystopic visions, perspectives mostly absent among the scientists themselves who have a more "business as usual" approach.

Chapter three, *The nanoscientific community,* explains how the researchers at MC2 are united by university experience, being part of a global community and coming from predominantly middle class backgrounds with financial resources and a will to pursue higher education.

Chapter four, *The lifeworld of the nanoscientist,* depicts how nanoscientists conceptualize themselves and their science as disembedded from society at large. What the researchers conceive of as culture becomes something extramural, something that belongs to the world outside the walls of science while intramurally, inside the walls, there are only individuals who pursue an objective and rational examination of the world such as it essentially is. The notion of nanoscience as disembedded from society at large is exemplified by how nationality, gender and religion are conceived of as irrelevant to research and cosmological conceptions.

Chapter five, *Experiencing nature,* portrays the nanoscientists' perspective of nature and how curiosity and beauty of nature are important in understanding the nanoscientists' cosmology. The chapter also describes how nanoscientists domesticate nature which is conceived of as inanimate, predictable and following universal laws. It is these assumptions of nature that are central to the researchers' conception of their science as objective.

Chapter six, *The Cleanroom and its technoscape,* presents how the extremely clean laboratory environment is used in nanoscientific research. Humans, acting in the cleanroom, need to control both their body and their behavior. For the researchers this body/mind control strengthens the idea of being objective since individually distinguishing characteristics are erased whereby a collective of similar looking peers doing similar observations about nature's true nature is created.

Chapter seven, *Epilogue: next to nothing,* ties the previous chapters together and argues that the nanoscientists, when doing research, reduce individualizing characteristics to a minimum. This process creates a perceivably universal scientist of "next to nothing."

2. Visions of nanoscience

Ideas of nanoscience in the public sphere are driven by future prospects of revolutionizing life conditions. The results produced by nanoscience so far, have, however, been modest. Today we can see how the term "nano" is used in advertisements for products such as frying pans, tennis rackets and windowpanes. In the future, however, the new science is envisioned to give us everything from faster computers and a cleaner environment to longer and more prosperous lives. These prospects serve as strong factors that influence governments to invest in nanoscience. It is estimated that governmental investment in nanotechnology on a worldwide scale has increased sevenfold from 430 million USD in 1997 to 3 billion USD in 2003 (Roco 2004: 1). In 2004, during the time of my fieldwork, approximately 40 countries had announced nanotechnology programs. Of these, the USA, Japan and the European Union accounted for more than seventy-five percent of the investments (Roco 2004: 2-3).

The development of science in general is politically often motivated by a utilitarian social aim. During the seventeenth-century visions of realizing a good society through scientific and technical innovation began to take hold in Western thought, a tradition continued by today's science (Rothstein 2003: 15). What makes nanoscience different from many other branches of science is the social significance of changes in the public sphere envisioned by politicians, financial analysts and funding agencies etc. The likelihood of the realization of the visions is strengthened by the notion that everything is constructed by atoms and therefore possible to manipulate by nanoscientists (López 2006: 17). At the extreme ends of nano visions are utopic and dystopic predictions. In between the two extremes there are a wide range of possible prospects and fears. Most of the nanoscientists in this study however, have a more "business as usual" approach, seeing nanoscience as a natural next step of science as it is today. Thus, there is a divide between two nanoscientific spheres; intramural nanoscience experienced by nanoscientists and extramural nanoscience perceived by the public. This divide is also seen when looking at the motivations for conducting nanoscience. Extramural visions of nanoscience are motivated mostly by utopic and dystopic visions while intramural nanoscience is motivated by scientists' curiosity, the domestication of nature and beauty. This does not mean that the scientists in this study lack visions of nanoscience, only that the visions are of another kind than those found among non-scientists in the public sphere.

Christopher Toumey (2004: 96-100) identifies no less than four genres of nanotechnological visions. First, there is the extreme nanophilic hyperbole which embraces the new technology uncritically with a clear utopian perspective. In this genre one finds science fiction writers and nano-advocates. Secondly, there are those who are positive but who do not embrace nanotechnology with the same optimism as the first group. In this genre funding agencies such as the North American National Nanotechnology Initiative are found. Thirdly, there are those who have a measured skepticism towards nanotechnology. Here one finds a few popular writers of science and, Toumey assumes, most of the nanoscientists. Fourthly, there are those who dystopically see nanotechnology as a threat to humankind, in an extreme nanophobic counter-hyperbole. In this genre one encounters science fiction writers, organizations and people working against the spread of nanoscience; one influential character being Prince Charles of Great Britain.

Being a not yet fully realized science makes it easy for both utopists and dystopists to fill nanoscience with their own agendas since the outcome is placed in the future about which it is only possible to speculate. Nanoscience in the extramural sector, therefore, fits well with the double understanding of the term "utopia" as "no place" and "good place," making utopia a non-realized good place. Despite the placement of utopias in the not here and now, it is important for proponents to present their future scenarios as achievable, thus separating utopias from dreamy make-belief. However, the futuristic scenarios of nanotechnology are not only impossible to verify, they are also hard to conceptualize as being plausible or not for most people. Some would argue that nanomachines that will destroy life on earth are a believable scenario while others argue that is pure fantasy (cf. Joy 2000). The concept of plausibility is connected to trust, making it important who is saying what. Is it believable for example that a nanotube cable with the thickness of a human hair could suspend a locomotive, as suggested by Ratner and Ratner (2004: 21)? Does the scenario become more believable if it is presented by a professor of Chemistry who also is member of the USA National Academy of Science? For a number of laypersons credibility increases.

Among nanoscientists the visions of nanoscience are generally not as grand as in the extramural sphere. Their view of nanoscience is founded on everyday experiences of dealing with experiments and deadlines. They are also all too well aware of problems facing the new science and they do not trust experts to the same extent as laypersons tend to do. It seems that their futuristic visions of nanoscience are founded in a "here and now" perspective which tends to make them more mundane.

The great divergence between science as understood by scientists and science as understood by laypersons seems to begin in the middle of the nineteenth century (Toumey 1996: 8). This mismatch creates "the conjuring of science" (Toumey 1996), where scientific symbols, such as white laboratory coats and technical terms, are used to give non-science the appearance of being science. Nano-advocates want to present their ideas of nanotechnology as scientific; a claim sometimes refuted by nanoscientists making it hard for the general public to recognize what is plausible and what is not (cf. Jones 2004: 7, Milburn 2002: 275, Toumey 2005: 22).

Visions of nanoscience in the extramural sphere

It is mostly in narratives of science fiction, placing the revelations in the future, that visions of extramural nanoscience are found (Crichton 2002, Marlow 2004, Stephenson 1995). According to Tony Miksanek (2001), nanoscience has become the norm in science fiction, and science fiction writers, if not including nanotechnology, must explain why. There have even been complaints among science fiction writers that nanotechnology is used like magic, ignoring physical laws and making everything possible (Landon 2004: 134-135), thus crossing the border between fantasy and utopian/dystopian narratives.

A person who has been an inspiration to science fiction writers and who probably is the most famous of the nano-advocates is Eric Drexler. In Neal Stephenson's novel *The Diamond Age* (1995), Drexler and other visionaries of nanotechnology have become heroes, portrayed in frescos on public buildings. The title "The Diamond Age" refers to an idea proposed by Drexler and Ralph C. Merkle, another nano-advocate; molecular machines would preferably be constructed by the hardest material around which are diamonds, hence naming the nanorevolution the diamond age (Merkle 1997, Drexler 1999).

In 1986 Drexler and other nano-advocates founded the *Foresight Institute*, a non-profit foundation whose purpose is to study and guide the societal impact of nanotechnology. This institute has become influential in promoting nanotechnology to the public but it also influences funding agencies. At least twice members from the Foresight Institute have participated in U.S. governmental hearings regarding nanoscience.

Also in 1986 Drexler published the first popular book on nanotechnology, *Engines of Creation: The coming Era of Nanotechnology*. In this work Drexler (1986: 4) makes a distinction between *bulk technology*, handling atoms in bulk, the technology we have today, and *molecular technology*, the handling of individual atoms and molecules. An example of this molecular technology is the invention of programmable molecular machines that he calls assemblers, which could build virtually any molecular structure, including exact copies of itself. The assemblers described by Drexler are constructed by mechanical objects such as molecular wheels, cogs and ratchets and he claims that biological systems are not any different from mechanical systems when it comes down to the nanometer level. Basically Drexler envisions these assemblers to be the solution to most human problems and he concludes (1986: 63) that nanoscience will create a good future society:

> Assemblers will be able to make virtually anything from common materials without labor, replacing smoking factories with systems as clean as forests. They will transform technology and the economy at their roots, opening a new world of possibilities. They will indeed be engines of abundance.

There is however a dark cloud hanging over the otherwise positive description of assemblers. The same nanometer machines that are predicted to give us abundance are also able to be our doom; a scenario which Drexler presents as the "gray goo" vision. In this scenario molecular assemblers start to replicate uncontrollably, dissembling matter to create new assemblers, leading to doomsday. This gray goo vision supposedly made Prince Charles of Great Britain speak out against nanotechnology, fearing a dystopic end of the world, which created anger among a number of nanoscientists (Björksten 2003). In a later book, *Unbounding the future*: *The nanotechnology revolution* (1991), Drexler et al. expanded on the future prospects of nanoscience: cheap solar energy, the end of the exploitation of nature, global wealth and a longer life span, being a few of the utopic visions.

Drexler's ideas of assemblers have come under fire from, among others, Nobel laureate Richard E. Smalley (2001) who wrote an article in the Scientific American with the telling title "Of chemistry, love and nanobots: How soon will we see the nanometer-scale robots envisaged by K. Eric Drexler and other molecular nanotechnologists? The simple answer is never." This is one of the few instances when scientists have entered the extramural domain to debate nanoscience within the realm of popular science. Smalley argues that there are at least two major problems with molecular assemblers, "fat fingers" and "sticky fingers." Self replicating assemblers will be too large to manipulate single atoms, having too fat fingers. Moreover manipulated atoms will stick to the assembler giving them sticky fingers. Drexler and Smalley continued the debate and Drexler has later seemingly withdrawn the idea of self replicating assemblers and gray goo as believable near future scenarios (Drexler & Smalley 2003, Drexler & Phoenix 2004, Giles 2004).

Drexler's choice of metaphors has intrigued social scientists. His envisioned progression of nanoscience has been compared to the conquest of the American frontier (Mody 2004). The first nanoscale images are compared to the first sighting of a new land, followed by the introduction of new technology in the form of nanogears, and finally introducing state control in the form of legislation and industrialization of the nanorealm. Drexler also uses mechanical metaphors instead of biological ones (Drexler 1986, Hayles 2004: 12-13). His idea is that matter, in the form of atoms and molecules, can be built and controlled like mechanics. His nanomachines consist of cog-wheels and ratchets, symbols of the old industrialization (cf. Jones 2004: 6). Drexler (1986: 286) even uses the term "biochauvinism" to describe the belief that biological systems are superior to others and that they have a monopoly on self-reproduction and intelligence. Self-reproducing nanomachines would be just as alive as a cell, according to Drexler (1986: 17). Cells are not to be perceived as containing a special life force compared to other structures and in theory therefore they can be constructed by humans in the same way that other structures are built. The difference between using mechanical metaphors instead of biological metaphors is the implied possibility of human control (Hayles 2004: 12-13). By using terms such as "engineering" and "building" instead of "mutation" and "evolution," Drexler suggests that we can build and control life itself as there are no differences between biological cells and mechanical machines. For Drexler as well as some of the other leading nano-advocates, this human control over matter seems not to end with life itself and he is also promoting cryogenics; the idea of freezing people after death hoping that future technology will make it possible to bring the person back to life. In a mechanical materialistic universe biological death is the end of existence and, as there is no afterlife, death is something to avoid. Thus avoiding death becomes a means in itself. By using nanoscience in cryogenics it is seemingly hoped that the new technology will release the advocates from the grip of death.

Less fantastic but still utopic visions of nanoscience are presented by various representatives of funding agencies. Even though funding agencies influence intramural nanoscience they belong to extramural advocates of nanoscience which gives them an ambiguous character. Their visions both allure the public and direct the scientists. One of the most influential of the funding agencies is the *National Nanotechnology Initiative* (NNI) handling funding in the USA. The organization was founded in 2001 with Mihail C. Roco as director. He has since become a leading political architect of nanoscience in the USA (Schummer 2004: 449). Roco's (2001, 2004) vision suggests that within a time span of 15-20 years nanotechnology will yield annually 300 billion USD in the semiconductor industry, affect half of all the pharmaceutical production, reduce worldwide energy consumption by ten percent, and even totally eliminate cancer related suffering and death. Nanotechnology will also diminish pollution and reduce our need for scarce raw material (Roco 2001: 7). In this way it becomes a technique which enables the continuation of industrial society without the collapse of nature.

Roco's utopia is realized through scientific innovations and guided by visions of scientific progression. Most societies, according to Roco, have not been interested in science at most points in their history. China and the Islamic civilizations were once in the lead before stagnating (Roco & Bainbridge 2002: 283). The same thing happened to the Roman Empire. The Renaissance meant a new beginning and technological and scientific advancement has continued unabated ever since (Roco & Bainbridge 2002: 282-283). What made the Renaissance special, according to Roco, is the holistic perspective; a perspective he argues it is time to recapture by combining nanoscience, biotechnology, information technology and cognitive science into what is often referred to as converging technologies. It is crucial for the future of humanity that these converging technologies will be successful (Roco & Bainbridge 2002: 294). Roco seems to see two roads for the future; a positive scenario in which nanotechnology together with other technologies will create prosperity, or a negative scenario, in which the convergence of different technologies fails, leading to poverty. Seemingly, Roco sees an affluent future with nanotechnology and an impoverished future without the new technology, meaning that his dystopia is a future without nanotechnology.

The utopian visions of nanotechnology proposed by the European Union regarding the future prospects of nanotechnology are modest compared to those that have been suggested in the USA. The European Commission (2004b: 28) argues that ordinary life will not change dramatically if nanotechnology becomes integrated into everyday commodities. In reports from the European Commission (2004a, 2004b) it is suggested that the contribution of nanotechnology will be computer chips so small and cheap that they can be integrated into almost everything enabling the construction of, for example, intelligent clothes that measure pulse and respiration. The reports also mention a few more futuristic applications such as “finger streets,” i.e. a road covered with small finger-like elements which transport objects by moving back and forth (European Commission 2004b: 44).

It is interesting to speculate about the differences between the visions found in the USA and in the European Union. Maybe the difference between the more utopic visions of nanotechnology proposed by Roco, representing the USA based NNI, compared to the less utopic visions of the European Union can be explained by the fact that the NNI is a governmental research agency with no equivalent in the European Union (Commission of the European Communities 2004: 8). The NNI is an active agent in promoting nanoscience, negotiating budgets, fighting other governmental agencies for money, and selling nanotechnology to the public and policy makers. Nanoscience in the European Union’s sixth framework program, a centralized research funding project, is just one out of seven priority areas. It has also been proposed that nanotechnology in the sixth framework program focuses on short-term applications and not on long-term science and the EU therefore lacks the long-term prospects that are so conspicuous in the USA visions (Berube 2006: 139). There are also studies which indicate that citizens in the USA are potentially more supportive of nanotechnology than citizens in Europe (Edwards 2006: 13-14, Gaskell et al. 2005, Johansson 2004, Mills 2006: 74). Since World War Two, USA governments have sponsored ground breaking research such as ENIAC, the world’s first computer, the Manhattan project, creating the first nuclear bomb, space programs that have placed humans on the moon and the internet. National research focused on nanotechnology would be a continuation of this tradition. In a highly speculative sense the general public in Europe may also be more suspicious of new technologies than people in the USA. For instance, genetically manipulated crops have been used in the USA for a long time while their introduction in Europe has caused a fierce debate.

The Feynman “creation myth”

Visions of nanoscience in the extramural sphere, looking towards the future, are at times founded in *myths of origin* that are used to support, maintain and confirm certain social orders (Barnard & Spencer 1996:

387). Myths of origin are used by certain groups for glorification and justification and to explain why things are as they are (Malinowski 1954: 125-126). Even in the tradition of utopias there is a call for myths of origin as the upcoming good society needs an originator, a so called Messiah who spreads the word (Rothstein 2003: 8). For advocates of both utopic and dystopic visions of nanoscience it is important to refer to serious science to get respect and promote funding. The point of departure varies, however, since different people will use different origin myths depending on what they consider to be the important aspects of nanoscience (Toumey 2004: 89).

Probably the most well-known extramural creation myth of nanoscience takes as its point of departure an event that took place at the California Institute of Technology, on December 29th, 1959. The physicist Richard P. Feynman (1960) held an after-dinner talk on the topic "There's Plenty of Room at the Bottom" in which he discussed the possibilities of building artifacts from single molecules and atoms. At the end of the speech he offered two prizes, one for building a tiny motor and another for writing in the nanometer scale. The prize for the construction of the tiny motor was claimed by the following year while the prize for writing in the nanometer scale had to wait until 1985 for a claimant (Regis 1995: 73-75, 143-145). As an anticipation of the coming utopic and dystopic developments of nanoscience the text chosen was Charles Dickens' *A Tale of Two Cities*, which, appropriately enough, begins "It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness." According to the myth, Feynman's speech and the competition he announced signified the birth of the present nanoscience.

The image of Feynman as the "father of nanotechnology" has been promoted by extramural nano-advocates such as Drexler and the National Nanotechnology Initiative. According to Drexler (2006) the revolutionary vision of nanotechnology was first described by Feynman and he even proposes that the forming of the NNI was motivated by Feynman's visions, thus ascribing him the role of the cultural hero behind nanoscience. However, according to Ed Regis (1995: 61), Drexler first discovered Feynman's speech twenty years after it was held. At this time Drexler's interest in nanoscience was already established which, according to Regis, proves the mythic character that the speech has acquired. It seems moreover, that scientific references to the Feynman speech started to increase in the 1990s (Toumey 2005: 18-19). The year 1990 can be regarded as a threshold with a steady increase of the term “nanoscience” appearing in scientific articles and in the same year the first scientific journal explicitly devoted to nanoscale science and technology was launched (Schummer 2004: 431). It was during the formative years, when nanoscience started to be separated from other disciplines, that there was a need for a foundation myth in the extramural sphere. The Feynman speech was thus appropriately rediscovered at the right time giving the new discipline a suitable origin (cf. Toumey 2005: 23).

The Feynman “founder of nanoscience” myth is interesting for several reasons. Firstly, presenting Feynman, a Nobel laureate, as the founder gives nanoscience credibility. Feynman is also often portrayed as a rebel genius and a bohemian (cf. Berube 2006: 49-50). By combining the seriousness and credibility of a Nobel laureate with a rebel genius one gets the perfect candidate for a myth of the origin of nanoscience. A discipline that might revolutionize society and shake it at its foundations needs an originator that is both credible and a visionary.

Secondly, the name of Feynman’s speech “Plenty of room at the bottom,” has entered “nano mythology” and become an expression used in the extramural dialogue on nanoscience, as an inside ironic joke. Irony creates an ambiguous status with an outer and an inner understanding, in which the inner understanding is only explicit for those who are initiated in the debate. For instance, when Smalley (2001: 77) argues against Drexler, he says that there’s plenty of room at the bottom but adds that “there’s not *that* much room.” Similarly referring to Feynman, Toumey (2005: 21) jokingly writes that a specific dystopic article could be called “There’s plenty of gloom and doom at the bottom.”

Thirdly, the Feynman creation myth serves a number of social functions. It gives nanoscience an American origin, serving USA policymakers to get more funding as it is important to assure the country’s continuation at the top. Feynman, being a Nobel laureate, becomes a guarantee for the reliability and seriousness of the new science, but at the same time by being described as a rebel genius he also becomes a guarantee of innovativeness and novelty. When former USA president Bill Clinton declared that "we have entered the nanoworld" and announced the National Nanotechnology Initiative at the symbolically loaded first month of the new Millennium, he did so at the university at which Feynman four decades earlier held his famous "Plenty of room speech." Clinton also referred to the Feynman speech. In contrast to the USA version of the origin of nanoscience, Feynman is not mentioned in the history of the science as presented by the European Commission (2004b: 6-7) which rather ascribes nanotechnology a European origin, referring to the ancient Greek philosopher Democritus, father of the idea of atoms. In the European version Democritus is followed by other European scientists, giving nanotechnology a pan-European origin. This European creation myth of nanoscience serves to pull the European Union together by proving that there is one coherent tradition of thought for all European countries and that nanoscience has a shared European origin.

It is also interesting to note that Feynman's inspiration to his talk might have come from a science fiction novel, linking science to science fiction. It seems that a friend of Feynman's had read a science fiction novel named *Waldo* written by Robert Heinlein (1942) and talked about it to Feynman at the time when he was composing his famous talk (Milburn 2002: 283). In the novel a genius named Waldo invents mechanical hands that master smaller hands giving the inventor the ability to manipulate microscopic materials, i.e. the method proposed by Feynman.

Conception of nanoscience in the intramural sphere

For the researchers at MC2 nanoscience is something lived and experienced by the testing of skills and acting in a technoscape, thus making research a mundane daily experience. The researchers' notion of nanoscience emerges through the constant testing of skills and through both successful and failed experiments. However, people in the public sphere mostly hear news about experiments that succeed. Thus, for those who routinely work with etchings, new coatings and carbon nanotubes and who daily experience the hardship of making these things work, the nanomachines that may take over the world and that are discussed in the extramural visions of the science seem far away. There is accordingly a contrast between experiencing nanoscience intramurally in daily life and imagining nanoscience extramurally. In this section the researchers' notions of their science will be examined. Later I will focus on the researchers' view of extramural visions of nanoscience, i.e. the researchers' view of how nanoscience is portrayed in the public sphere. While extramural visions of nanoscience are commonly based in utopic or dystopic expectations, nanoscientists' intramural visions of nanoscience have their base in a here and now perspective.

Most of the nanoscientists' machines and skills have been developed for experimenting on the micrometer level and subsequently they have been employed to discover the nanoworld. This transference explains why researchers at MC2 perceive nanoscience as the continuation of conventional natural science and not as something radically new. A researcher explained to me that the principle behind the motor used in today's cars is over one hundred years old and in a similar manner the lithograph process on silicon will be marketable 100 years from now. "There will be no revolution with nanotechnology" he added. Nanotechnology, according to this researcher, will create good sensors and faster computers but we will not have computers driving cars by 2020 since the human brain is hard to beat. The researcher concluded by saying that it is problematic to make commercial products with nanotechnology as nanomachines need very low temperatures to function and commercial products need to work in room temperature. There are consequently two reasons behind the researcher's lack of enthusiasm for nanohype. Firstly, nanoscience is seen as just a continuation in the process of domesticating nature and not of a new revolutionary branch of science. Secondly the daily experience of working with nature makes the researchers fully aware of the problems of constructing commercial products in the nanometer scale.

Another researcher working with finding new materials for constructing computer chips was likewise telling me that nanoscience is the normal continuation of material physics, the sub-division of physics that studies properties of materials. Physics, according to the researcher, has always been doing nano, as physics deals with atoms and molecules. Electronics is developed today on the nanometer level and if one is interested in working with electronics one has to become a nanoscientist since this is the level on which research is conducted. Nanoscience, in accordance, is just normal physics conducted at the nanometer level. From the scientists' perspective the nanoworld opened up for manipulation during the 1980s when new types of microscopes first allowed researchers to create images of single atoms and then, later in the decade, to get in direct contact with them. Among the researchers, therefore, nanoscience is seen more as a technical advancement than as a new science.

The researchers' conceptualization of nanoscience as a continuation of normal science contributes to their perception of their science as being ethically unproblematic. At a nano-conference at Chalmers University of Technology the introductory speaker told the audience that nanoscience was just "business as usual" in a brief mentioning of ethics. This "business as usual" approach was also seen at a conference on nanotechnology held by the Swedish Research Council's ethics committee in 2004 in an attempt to start a debate on ethics among natural scientists. The ethical problems discussed were principally regarding the corrupting power of research money from corporations and that nanosized particles might be bad for humans if they got into the body. One participant voiced a worry that nanoscience might be used in the future to control emotional states, but concluded that "… we already do that with psychopharmaceutical drugs." The ethical problems discussed were practical issues found in most branches of natural science. At this conference I happened to sit next to an employee of the Swedish Research Council who gladly told me that he had never heard of nano before the conference, but that this condition would not affect his understanding since the ethical problems were just the same as for other sciences.

With the researchers' attitude towards nanoscience as a continuation of existing science in a "here and now" there seems to be no need for an intramural myth of creation. Feynman is principally known for his formulas and not for his 1959 speech and it is therefore no surprise that the Feynman creation myth is unknown by many of the nanoscientists at MC2. History is of little concern for the researchers and nanoscience is conceived of as timeless; a timelessness apparently shared by other physicists (Traweek 1988: 86). This ahistoric perspective was made clear to me during a coffee break discussion on how the formulas of Isaac Newton were still valid today. When I started to fill in about the life of Newton, describing his passion for alchemy, I discovered that the scientists only knew about the formulas, the part of Newton's science that I did not know. Newton is accordingly known among the researchers because they use his formulas and not because he is an important person in the history of science. During their training physics students learn formulas named after famous physicists but they do not learn about the physicists themselves, as this is conceived of as superfluous knowledge of little concern to the practice of science. To have objectivity as the standard for research means that human agency is reduced to a minimum and formulas are seen as representations of natural processes that are eternal and therefore without history. The formulas presented in textbooks, for example, are there because they are useful in the present, the here and now perspective, and not because they were useful or important in a historical perspective.

During my fieldwork I did not encounter any stories among the researchers at MC2 with a clear utopic or dystopic vision of nanoscience. However, on one occasion, a researcher to whom I had introduced the writings of Drexler told me that instead of writing about Drexler's assemblers which in his opinion was nonsensical, it would be more relevant to write about nanoresearch done by NASA. According to the researcher, NASA aimed to make it possible to give orders direct to soldiers brains by planting computer chips in them; a vision that assumedly will come true in the coming 10-20 years (cf. Hoag 2003). He continued:

> A brain is a complex computer and maybe in the future a brain chip can store information from a dead person. If the brain is damaged a computer chip replaces the damaged part, the same might be possible with mentally handicapped persons.
>
> When I replied that it sounded like science fiction he responded:
>
> This is not the same thing as nanorobots reproducing without control. The nanorods [used for the interface between the chip and brain] are between 1 to 20 nm wide and research on them

> is done in Sweden. There are good and bad things with the new technology, the bad is that they can be used by soldiers and terrorists and the good is that they can be used to cure mentally handicapped and blind people—this is reality, not science fiction.

This vision and the few others that I encountered among the researchers was based on the everyday experience of science. The researcher mentioned above is careful to point out that the science on computer/brain interaction is done today and by referring to scientific articles he gives his vision a foundation in contemporary science.

The introspective gaze on nanoscience as mundane and based on a here and now perspective also affects the researchers' view of extramural ideas of it. A handful of researchers told me that they resented that the term "nano" was used as a sales pitch to the public. At one time a researcher got quite agitated when he was buying a frying pan and discovered a "nano frying pan" on the store shelf. He refused to buy it and later told me that the term "nano" has become a way to con people out of their money. For the researchers, technology is in focus as it is this which enables them to manipulate the nanoworld and not the nanoworld in itself. Extramurally, though, the nanoworld often comes into focus and not the means of how to reach it.

A similar resentment with regard to the extramural use of "nano" was described by researchers in their contact with funding agencies. A senior scientist active in fund raising described the whole concept of nano as a bit of a fraud to fool funding agencies. Basically physicists and chemists are doing the same thing as they have done all along, changing properties on an atomic level, it is just that today they are using the word nanoscience to describe it. This means, the senior scientist told me, that many researchers are doing nanoscience without using the term. When the term "nano" becomes a means for obtaining funding, researchers wake up and start to use it and suddenly there are plenty of nanoscientists who are doing the same things as they did before.

The discrepancy between extramural and intramural attitudes towards nanoscience is further enhanced by the fact that most nanoscientists do not participate in nor take part in public discussion of the science (cf. Karhi 2006: 92-93). The debate between Drexler and Smalley, for instance, was not well known among the nanoscientists in this study since it was an affair that principally was conducted in the extramural sphere. Late on during my fieldwork I introduced Michael Crichton's science fiction novel *Prey* (2002) to a handful of researchers. In the book a cloud of self-sustainable nanomachines escape from a laboratory and start to prey on humans and other organisms. Those who read it thought it was a hilarious story, but of no relevance for them as researchers as it lacked a factual base in science and was therefore considered to be unrealistic.

One reason why the utopic and dystopic visions of nanoscience that blossom extramurally are not challenged by researchers, is the scientists' general disinterest in extramural visions of nanoscience. That Eric Drexler, probably the most famous extramural nano-advocate, is not well-known among the scientists came as a surprise to me when I started my fieldwork. Those who knew of him were some professors and senior researchers, that is, people active in science policy, and they were skeptical. One of the professors told me "no real scientist believes in self-replicating nano machines." Since one of my standard questions to the researchers at MC2 was about Drexler, I discovered after a while that I had initiated an interesting process of imagining, as the scientists started to ask each other "who is this Drexler guy that Mikael is asking about?" I started to receive imaginative replies as to who Drexler is. One of the researchers I talked to told me that Drexler was a professor in biotechnology, a field not known to the interlocutor.

The disinterest in extramural visions of nanoscience is partly caused by the researchers' ambivalence towards the media. There seems to be a general feeling that scientific results often are distorted by the media to create utopic and dystopic visions among the public. Experimental work that has been produced through hard labor in a single sample is sometimes presented as a finished mass-produced product. In a few cases the reluctance to talk to the media meant that I needed recommendations from colleagues to arrange for interviews with their fellow researchers. At one time I wanted to interview some Russian researchers but was told by others that they were not too keen to talk to me. I then contacted a researcher whom I had met earlier who worked in the same research group as the Russians and asked him to assist me in getting them to work with me. After a while the researcher contacted me and told me that the Russians were not interested, the only time I was refused interviews. The reason for their reluctance to talk to me was probably grounded in a suspicion of what the interviews were to be used for. The researcher tried to comfort me with a story one of the Russians had told him. It was during Soviet rule and *Pravda* wanted to interview the researchers who, however, were not too thrilled about participating. The request wandered down through the hierarchy until a PhD student ended up talking about his research. Although the PhD student's project was considered mediocre by his fellow colleagues, *Pravda* ran a story the following day about the great discovery that had been done at the laboratory. The PhD student was laughed down by his colleagues. "That is why some Russians will not be interviewed, they are suspicious," the researcher told me.

To have ones' scientific results portrayed as ground breaking in the extramural sphere seems to be of little importance for many of the researchers. The fear of making a fool of oneself intramurally, however, among colleagues is more important, which comes from being part of a community where credibility is important. A senior researcher told me that to succeed as a researcher one needs to be a good scientist as well as being able to build a broad network which is important for seeking funds. "Everybody knows everybody in the business and it is important to be considered seriously to get funding. One must make a name for oneself inside the network," the senior researcher told me.

To actively seek out the media is also something which may be looked down upon, especially if ones fellow researchers question the actual value of media exposure. At one time during my fieldwork I saw a TV news report about ground breaking nanoresearch being conducted by a research group at another Swedish university. When I asked about the news report I was told that three other groups had previously done similar research, implying that the discovery was not new. Another scientist commented that it all had to do with money; the group wanted more resources and therefore it had turned to the media, fully aware of the previous research in the field. Others expressed surprise that the group had gone to the media with a discovery considered not to be theirs: "the whole story is embarrassing," one of the researchers declared. Several of the scientists at MC2 who knew about the news report thought that the media exposed research group had acted unethically by going public, getting credit for other peoples work and trying to use media exposure for attracting funding etc. An interesting observation was that several of the researchers at MC2 to whom I talked about the matter thought that the media exposure was not only an embarrassment for the exposed research group but also embarrassing for the whole nanoscientific community.

MC2, constructing a formula of science

The construction of the MC2 facility is founded on extramural visions of how natural science and engineering will make Sweden prosper. The Gothenburg region has traditionally relied on manufacturing industries and its shipyards; branches of business that started to decline in the 1970s. In 1990 Sweden entered a long recession, forcing the government to cut costs, leading to rising unemployment. As an escape from the recession the government had a vision of transforming Sweden from an industry-based country to a knowledge-based country, leading to a massive build-up of the university system. Between 1991 and 2001 the number of registered students rose by sixty-two percent, the number of PhD students rose by ninety percent, and the number of universities rose from seven to thirteen (Vetenskapsrådet 2004: 9).

The vision of how to make Sweden into a utopia, a good society, is clearly seen in a governmental report called "Innovative Sweden—A strategy for growth through renewal" [original title in Swedish; Innovativa Sverige: En strategi för tillväxt genom förnyelse] (Ministry of Industry, Employment and Communication & Ministry of Education and Science 2004). According to the report, Sweden should not compete internationally by lowering wages but instead compete by strengthening education and research. The report continues by arguing that Sweden has about ten new strong industrial fields, of which one is microtechnology, and that invention is the most important sources for economic growth and prosperity in the long run.

The governmental report continues by stating that future inventions will come from a strong knowledge base, making it important to increase children's interest in mathematics, technology and the natural sciences. The long term goal is that half of the population should have started to study at college or university by the time they are twenty-five years of age (Ministry of Industry, Employment and Communication & Ministry of Education and Science 2004: 18). The Gothenburg region is included in this vision and the local municipal commissioner, Göran Johansson, has said in an interview that he looks at the future with confidence regarding the transformation from an industrial city to a university and knowledge based city (Riise 2002: 12); a view seemingly supported by the people of Gothenburg who considered higher education and research the most important activities for regional development (Lundborg 2003: 9).

Nanoscience is part of this "utopia through invention" vision and according to an evaluation made by the Swedish Research Council (2002: 34) "The MC2 laboratory is certainly a world-class academic facility and is, therefore, very important to Sweden." It is easy to imagine that the utopic visions of nanoscience are attractive to politicians and policy makers and how the MC2 facility therefore is seen as an asset of both regional and national interest. However, the visions of nanoscience found in the extramural sphere stand, as we have seen, in stark contrast to the visions found among the researchers, and this also influences how the two spheres respectively conceive of the establishment of the MC2 facility. Extramurally the laboratory is hoped to serve as a motor for the region's industrial and economic development while intramurally the majority of the scientists seems to have only vague ideas about why the MC2 facility was built.

With regard to the background leading to the establishment of the MC2 laboratory the researchers form a community without history. Few were interested and I only got bits and pieces of the facility's history until I happened to meet one of the initiators behind its construction. According to him, Chalmers University of Technology wanted to gather everything dealing with microtechnology under one roof during the 1980s. In those days microtechnology had the same status as nano has today; it was a buzzword used in all types of connections. The professor was called to a meeting with the Prime Minister to explain what microtechnology was and to lobby for a new microtechnology centre. In those days, I was told, all governmental building projects were on a priority list and those at the top were built first. This meant that the future MC2 had to compete with, for instance, public swimming baths that were also placed on the list. To speed up the process of gaining a place for the future MC2 as high up on the list as possible, a consultant was paid by Chalmers at the end of the 1980s. With a shift of government in the early 1990s, the right-wing government decided to allocate funding from the wage-earners' investment funds, created by the Social Democratic government, to pay for the future MC2. The Social Democrats were not too happy that the right-wing government had taken the wage-earners' investment fund to pay for research and, according to the professor, the subsequent Social Democratic government treated MC2 badly. Another problem at this initial phase was to keep the professors of the different microtechnology groups together and to prevent them from going to other universities. This was nine years before the project was completed and "I had to run like a shepherd's dog to keep the flock together," the professor told me. It was also problematic to find a location for the new facility and since new land was not available, the new building had to be located on the existing Chalmers premises. The different sections at Chalmers initially showed little interest in the microtechnology building. However, in 1993 the right-wing government promised money for the project and an internal tug-of-war started at Chalmers. After negotiations between the different departments it was decided to place MC2 at the physics department. The only place available near the physics department consisted of sloping rock but it was still chosen as the place for MC2. Construction started but problems continued as the Social Democratic government withdrew its yearly rental subsidy towards MC2 arguing that Chalmers could use the money received from the wage-earners' investment fund, making MC2 fully supported by Chalmers alone. In June 2000 the construction of the facilities was finished. A year and a half later, MC2 became an independent section directly under the Chalmers board. Looking back on a project on which he had worked for approximately fifteen years, the professor concluded "it was one hell of a job."

Figure 1. The MC2 facility.

The professor's story, as told above, is not one about utopic visions of prosperity but more about how he had to fight politicians and fellow researchers to construct the new facility and keep the different research groups together. It is also a story based on a mundane here and now perspective, as the initiative behind the building came from a practical idea of placing all research groups dealing with microtechnology in one building to pool resources. This does not necessarily mean that the professor lacked visionary notions about the construction of MC2, just that he did not mention them in the interview.

The intramural notion that nanoscience has been hyped is also found among sectors in the industry. Industrialists, I was told, are interested in making money "here and now" or at least to make a profit in the near future. As nanoscience has thus far only had modest applications, the industrial interest in Sweden has been low (Wallerius & Westman 2005). This is indicated by the fact that in 2003 only two percent of the total number of working hours in the cleanroom facility at MC2 were contracted by external users. At the time of my fieldwork the two major industrial cleanrooms in Sweden had been closed due to high expenses and I was told that most Swedish companies might be too small to be able to cover the costs. With a construction cost of €90 million and a yearly maintenance of €5.5 million, not counting the research expenses, facilities such as MC2 are only affordable to large corporations. I was also told that Swedish industry was not willing or able to carry the costs and therefore nanoscience nationally is principally a governmental affair created on extramural beliefs of envisioned future prosperity. This, in turn, adversely affected the number of nanoscientific industrial jobs available in the country, leading to unemployment. Some researchers told me that the skills they got at university were of little use for Swedish industry as it is now making products from university research conducted approximately ten years earlier; forcing them to go abroad to get jobs matching their skills.

One way to explain the government's interest in paying for research that is not directly applicable to the industry is to examine the interdependence between science and the state. Scientists can be seen as an *elitist reserve labor force*, serving as a talent pool to give legitimacy to the policies of government (Mukerji 1989). In a broad sense science is an essential part of a modern state and governments are therefore willing to pay for research. By accepting central funding, researchers lend their authority to governmental officials who use science to realize their political agendas. Therefore, by seeing the nanoscientists at MC2 as part of an elitist reserve labor force, there are at least two reasons for the government to pay for nanoscientific research. Firstly, the nanoscientists serve as the means to realize the politicians' visions of nanoscience; they become emblems of utopia, servants working towards the good society. Secondly, when nanoscience becomes industrial technology Sweden will have a labor force ready to put on the production line.

Summary

In conclusion, there are two broad notions of nanoscience. Extramural visions of nanoscience, found in the public sphere, are based on utopic or dystopic visions while intramural nanoscience, found among the researchers at MC2, are based on a here and now perspective. Extramural interest in nanoscience is motivated by visions for the future found among politicians, funding organizations and other nano-advocates. Intramural nanoscience, in contrast, is based on the researchers' daily labor, dealing with experiments and testing of skills, giving them a skeptical attitude towards extramural visions of their science. The scientists' motivation for conducting their research is instead founded in the curiosity, aesthetic and domestication of nature, as will be examined later on in the thesis.

One of the most well-known advocates and utopists of nanoscience is Eric Drexler who in 1986 distinguished between contemporary technologies dealing with atoms in bulk and future molecular technology dealing with atoms and molecules individually. The USA based *National Nanotechnology Initiative* is arguably the most outspoken of the funding agencies. The visions of nanoscience as proposed by the director of the NNI are less utopic than those proposed by Drexler but more utopic than those proposed by the European Union. In a speculative sense these differences are caused by different organizational structures and cultural attitudes between the USA and Europe.

Among the researchers at MC2 nanoscience is not perceived as something radically new but instead as a normal continuation of existing science, handling machines that have originally been constructed to deal with phenomena at the micrometer level. Nanoscience, for the researchers, is something lived and experienced, thus making it part of their daily life in which failed experiments are common. Accordingly, there is a contrast between experiencing nanoscience intramurally and imagining nanoscience extramurally. Intramural notions of nanoscience seldom come into contact with the extramural ones. This means that extramural creation myths, such as the Feynman story, and nano-advocates such as Drexler, are not well known among the researchers. Among many researchers at MC2 the extramural visions of nano are not serious and therefore unimportant.

3. The nanoscientific community

Scientific communities are based on a labor identity which means that belonging to such a community is an active choice and that membership is reached by acquiring expert knowledge and skills through university education. A community based on labor identity also means that the members have private lives outside the community, and that there is a notion of separation between the private and the working sphere. Together the researchers at MC2 constitute a scientific community in the sense that they form a group of people with a common educational history, hopes of a common future, and, most importantly, that they see themselves as a group in contrast to other groups (cf. Traweek 1988: 6).

As mentioned earlier the nanoscientific community emphasizes individualism and it is thus constructed and maintained by an intricate play between the collective and the individual. Individual global networking with research groups outside MC2 is constantly in the making as each individual constructs his or her own global network of peers. A number of researchers at MC2 have more contact with foreign research groups than with local colleagues, thus making this community of nanoscientists an entity that not only consists of researchers at MC2 but one that in a literal sense is truly translocal. Consequently, as a community it is rather peculiar in that in many respects it is ego-centered rather than spatially circumscribed. This ego-centrism also means that individual networks differ from one another and therefore the community at MC2 has an *amorphous* structure. The ego-centrism of the community is also found when the researchers describe themselves. The term “nanoscientist,” for example, is used by some but not by all of the researchers in this study to describe themselves as a group. Others see themselves as physicists, material physicists, electrical engineers, physical engineers, or just plainly as scientists.

What principally keeps this straggly group together is the shared understanding of physics and the experience of handling matter at the nanometer level, which are the same factors that differentiate them in relation to laypersons. The researchers have a largely shared perspective of perceiving and acting in the world but, at the same time, they exclude all those who are not trained nanoscientists. A majority of those who are not part of the nanoscientific community have for instance neither the proper knowledge nor the skills to produce or to understand nanoscience. Underwriting this perspective a teacher in a course said "you will belong to the top five percent best educated people in Sweden… Be confident that you have the knowledge, and that you have an obligation to teach that knowledge to the public" while another teacher in the same course told the students "'New Age' still exists because it explains technical and medical things in a way people understand. For ordinary people technology and magic are the same." Such observations stress the researchers' knowledge and skills as distinguished markers of their community.

Even if researchers in the nanoscientific community are aware of individual differences between themselves they also recognize that when it comes to science they have more in common than they have with those outside community. Important factors uniting the nanoscientific community are the university experience, the global character of the community, and that most new members are recruited from the global middle class. During undergraduate studies the students' time is principally devoted to on campus activities that strengthen intramural social networks at the expense of extramural ones. The globalness of the corpus of researchers, with people coming from all over the world, also promotes the creation of a community in which several of its members form intramural global social networks at the expense of extramural local social networks. By recruiting members from the global middle class with similar academic backgrounds a certain feeling of being socially at home in the scientific environment occurs, no matter the geographical location. Being part of a global community that plays down local differences in favor of commonalities also helps to underwrite the notion of nanoscience as objective and beyond national borders, politics and other regional differences.

The local community

Becoming part of the nanoscientific community at MC2 begins by being accepted and then socialized as a doctoral student, a process involving both the developments of individualizing skills and an adjustment to the expectations of the collective. By learning physics a shared set of meanings are transferred to the students giving all nanoscientists common cosmological conceptions. At the same time, skills are acquired individually creating personal careers. Skills in, for instance, advanced mathematics serve both as a collective characteristic unifying the community against outsiders and as individualizing characteristics. Nanoresearchers generally have a better understanding of mathematics than most laypersons but the level of mathematical understanding and specialization differs between individuals within the community. For example, with regard to mathematics the theorists have a specific focus and interest that differs from that of the experimentalists, who more commonly focus on the handling of machines rather than on producing theoretical models.

Undergraduate studies monopolize students' time and they spend lots of time on the university premises. Moreover, to be able to pass exams in physics the participation in study groups is important and the formation of such groups is therefore encouraged by the various departments. These groups not only facilitate the studies they also constitute important "cells" in which a collective socialization of the students takes place. Students with no help from their peers have a hard time passing exams creating an effective exclusion process (Hasse 2002). An undergraduate student in physics told me, when discussing study groups, that besides the book studies, social relations were the goal of the education. He continued by saying "Leonardo da Vinci will not come again, physics today is too complicated and one needs to work in groups. The social part comes naturally, but I learn to take crap, compromise and so forth." The many dropouts among the students also assists in creating a close knit community of the survivors where the members are aware of their mutual dependence upon each other. A recently accepted doctoral student at MC2 told me that during the undergraduate education several things are learnt besides the fundamentals of physics, such as critical thinking and an ability to cooperate. She also noted that during this time she started to use mathematical and physical terminology in normal conversations making similes between physics and everyday reality. The education moreover meant a process where she learned how to express herself in a manner that she described as scientifically correct, i.e. learning how to write scientific reports in an objective way.

Thus, to become a physics student signifies much more than just taking academic courses. A shared set of meanings emerge through the practice of everyday experience and those who cannot adjust are excluded. The inclusion process, in contrast, involves learning how to cooperate, how to behave properly in the university environment, and how to think scientifically etc. Studies also monopolize the students' time making the intramural social networks important for future academic success. The doctoral student referred to above noted that she did not have much contact with people outside the department of physics and that Chalmers was like a huge magnet when she reflected on her university experience. The process of fitting in also includes clothing and behavior styles. After spending a year at MC2 I was struck by the homogeneity of the people. What meets the eye is a group of mostly males with short hair, shirts and jeans or Docker-like trousers. Sub-culture groups such as hard or punk rockers or hip-hoppers are conspicuously absent. Researchers dress with moderation and do not stand out. Apparently the dominant tendency is not to be too different from one's peers. In a speculative sense, those who stand out may have a harder time establishing research networks than those who do not.

The exclusion process continues during graduate studies and beyond and eventually creates a community of a selected few. To become accepted as a doctoral candidate one needs not only skills but also social connections. It is the individual skills that make a person competitive and able to join the collective but it is not an automatic process since it requires the approval of people inside the community. Professors told me that they did not automatically accept those with the best grades for graduate studies because having good grades is not the same thing as being a good researcher. A good researcher is seemingly someone who fits into the group without causing social tension, who is even tempered and who is prepared to work many hours.

Only a few positions for doctoral studies are advertised publicly since their existence spreads through the researchers' grapevine. Commonly the researchers at MC2 have achieved their position or become accepted as doctoral candidates by recommendation. It is consequently important for potential candidates to have the right social connections to be able to apply for a position. One of the present researchers at MC2 was among the best physics undergraduate students at his home university and because of his qualities he was well known among the senior teaching staff. When a physics professor from his university visited Sweden he told a professor at Chalmers about this brilliant student. The Swedish professor had a need for a doctoral student and on the recommendation of his colleague he accepted the new candidate. This process of accepting doctoral students is not only a way to get new qualified group members, it also creates and strengthens social bonds between the giving and the receiving research groups.

Once accepted as a doctoral candidate the student becomes part of a research group which influences their future choices inside the community. The kind of professional skills to be learned by the candidate are decided by the research group since each group has its own specialty. For example, if a student is accepted to the photon group he/she will work with photons which require a certain specialization commonly dealing with different types of lasers. The learning process of the doctoral student, thus, becomes an affair for the whole research group. The individual skills learned during doctoral studies often require instructions from the whole group, and each individual researcher contributes his or her own expertise to form the new member of the group.

A typical research group consists of a full professor, associate professors, postdocs and doctoral students; altogether between 15-30 people. Even though the composition differs between the various research groups approximately half of the members commonly consist of doctoral students. Moreover, the members of research groups tend to be in flux because some people leave while others join for a longer or shorter time. The most permanent member is the professor, who is at the centre. The importance of the professor is indicated by the fact that, as professors are assigned to a new university, it is not uncommon for fellow researchers in the group to also move along. A senior researcher who originally came from another Swedish university told me that it was natural for him to accompany the professor of the group that he was member of when the professor got a new position at Chalmers. The professor had been his unofficial thesis supervisor and later he became a colleague and personal friend. Similarly all the other senior researchers in the group were colleagues at the first university and they had all moved to Chalmers. As most of the research money comes from external sources it was easy to move. When the professor decided to move once more the same senior researcher decided not to move since he had got a permanent position at the department. Other senior researchers of the group who did not have permanent positions decided once more to uproot themselves and their families and follow the professor to his new position. As the example illustrates, personal careers are tied both to the research group and to individual choices. Research specialization and moving to a new research facility are not always decided by the individual but each person has at the same time a choice to stay in or to leave the group. Consequently, throughout a whole career it is common to have belonged to more than one research group.

To move from one research group to another is usually not seen as negative since scientists in different research groups partake in processes of mutual exchange. By exchanging experimental results and assisting each other with producing and analyzing samples people in different research groups co-produce articles together. This increases the number of publications each individual is involved in compared to if each scientist had to conduct all the experiments in an article by themself. A way to tie researchers together to form future alliances is through exchanging postdocs and doctoral students. Instead of having two groups forming an alliance through marriage the exchange of postdocs and doctoral students serves a similar purpose and such exchanges become a means of pooling resources (cf. Traweek 1988: 106-109). To exchange a scientist thus becomes a process with three winners. The receiving and giving research groups become tied into networks used for improving the probability of receiving funding in cooperative research projects. Also the exchanged researcher, who becomes the interlink between the two research groups, not only increases his or her social network but also learns new skills from the new research group. A researcher who did his postdoc in France told me that he went there to get a perspective on his own work. By talking daily to his French colleagues and being in another environment he got new insights on how to conduct science. New social bonds were also created which he later used for applying for EU grants requiring the involvement of at least three European universities.

The forming and reproduction of a closely knit nanoscientific community is achieved through strengthening intramural social networks at the expense of extramural ones. As students at Chalmers, future nanoscientists can live their lives on the premises since there are student dorms, restaurants, pubs, training facilities, bookstores, computer shops etc. inside the university area. These intramural networks are reinforced by a feeling of autonomy, in which universities become free zones separated from the rest of society. This autonomy was expressed when people told me that they had a choice between working at "Chalmers or in reality." Working "in reality" was to work for a company constructing things that would reach the market while working at "the university" was ideally to experiment freely without having a company to account to.

A manifestation of the autonomy experienced from the rest of society is seen in figure 2, next page, that are taken at the crossing just outside the main entrance to Chalmers. On the lower left picture the "no crossing" sign is unaltered while in the picture to the right the sign has been manipulated to look like the cartoon character Lucky Luke; the "patron saint" that students have "given" to one of the engineering schools at the campus. The manipulated sign is on the side of the campus while the unaltered sign stands on city ground. The manipulated sign has been altered several times while the sign on the left has remained unaltered, as far as I know. By conducting this prank, undergraduate engineering students distinguish between the intramural Chalmers side and the extramural city side between which the street serves as a concrete border.

Figure 2. Road crossing at Chalmers main entrance.

Examples of the experience of universities as free zones separated from the rest of society came up in interviews from time to time. A physicist who had been working in the former Soviet Union told me that universities during that time were not controlled so firm by the state and most of the scientists cared only about their research and were not that interested in politics. This was at a time in which the whole of society was part of a political project. Another researcher with a similar background in a dictatorship described how the university in his country was a closed area from the police and therefore how the premises were used by people who opposed the government.

The global community

The scientists' notion of belonging to a global community can hypothetically be divided into three parts. Firstly, a global community is constructed by separating the extramural world of civil society from the intramural world of research. Since being a nanoscientist is a professional identity it is also possible to create a private life outside the scientific community that is of no concern for fellow researchers; thus creating a difference between intramural and extramural life. Secondly, the feeling of being part of a global community is strengthened by the closely knit international cooperation between research groups. Thirdly, by excluding extramural local civil society and stressing international cooperation a self-identification of being part of a global community is created.

The perceived disembeddedness of the global nanoscientific community from the local extramural society was described by scientists at MC2 in different ways. A researcher told me what he conceived two parallel societies, an ordinary and a scientific. The scientific society he saw as international while the ordinary society was conceived of as local. The condition that the nanoscientists speak English instead of Swedish and move between different laboratories around the world also contributes to a conception of disembeddedness from the extramural local community. A foreign scientist who had been living in Gothenburg for four years did not find his way into the central area of the city. When asked about it he said "I do not travel that much into town." This view was supported by others who said that they mostly just traveled between work and home due to the heavy workload and not having time to socialize outside the scientific community.

As most of the foreign researchers at MC2 do not plan to stay in Gothenburg or Sweden for any length of time they do not learn Swedish. A researcher at MC2 whose previous international career included a postdoc project in France and a research position in a German laboratory declared "I cannot learn a new language every time I move." English becomes for the scientists a marker of being global and at the same time it distances the foreign researchers from the local Swedish speaking community. Similarly, a researcher who went to South Korea to do some work told me, when I asked him about the country, that he was there to work and not to learn about Korean culture. Being global in the nanoscientist's way is not the same thing as being cosmopolitan. Ulf Hannerz (1996: 103) points out that cosmopolitanism includes a willingness to engage with the "other," an attitude that seems to be rare among nanoscientists.

Worldwide scientific cooperation is part of being a global community. According to researchers at MC2 there are no cultural clashes within international cooperation as those who work internationally are so used to it. A professor who was the head of a national project told me that he was cooperating with national projects of other countries tying them into an international collaborative network. I was also told it was often easier to cooperate with other international groups who were not competing for the same national funding as projects from the same country. A researcher noted in a similar manner that the scientific community is held together by people who all share a common interest and that researchers only feel disciplinary borders, not national ones.

In short, scientists at MC2 conceive of their community as global in the following manner; they come from all over the world and nationality is of no concern to them. Out of 203 researchers at MC2 nearly half are non-Swedes. Since guest researchers are not accounted for in these numbers, almost all of whom are from abroad, the actual percentage of non-Swedes is even higher. Apart from Swedes, Russian scientists constitute the largest national group followed by the Chinese. All in all, 29 nationalities were represented when I initiated my fieldwork.

> Nationalities and number of researchers, May 2003.
> Sweden: 120, Russia: 27, China: 8, Iran: 5, Canada: 4, Italy: 4, Bulgaria: 3, France: 3, Germany: 3, Iceland: 3, Spain: 3, India: 2, Sudan: 2, United Kingdom: 2, Armenia: 1, Australia: 1, Bangladesh: 1, Belgium: 1, Finland: 1, Iraq: 1, Korea: 1, Latvia: 1, Malaysia: 1, Norway: 1, Pakistan: 1, Philippines: 1, Poland: 1, Sri Lanka: 1, Tanzania: 1.

One of the most conspicuous aspects of the lack of national markers is the general use of English, a language few of the researchers have as their native tongue. An administrator told me that "people at MC2 are a culture of their own. Our culture consists of being international and speaking English." For those researchers who for a long time have been part of this global community this is routine, but for newcomer it is something that is reflected upon. A recently accepted doctoral student explained: "The first couple of weeks at MC2 I thought about the use of English and that it makes you feel international." English is the *lingua franca* of MC2, an international language to ease communication between people with different first languages. English therefore gets an aura of being international and is perceivably owned by no one.

Even if the nanoscientists move through the global labor market, principally having the whole world as their workplace, they also follow international monetary flows. Only rich nations are able to support substantial nanoresearch programs and it is in those nations that the researchers are found. Most of the non-Swedish researchers at MC2 come from countries that have difficulties financing their own nanoresearch, such as Russia, India and Iceland, or from countries that, at the time of my fieldwork, were just starting up their research programs, such as China and Korea. In contrast, researchers from the USA and Japan come from nations who are themselves major players in nanoscience and they are not so interested in doing research in Sweden. Nanoscientists therefore interact in what is called an *intra-space mobility* meaning that they travel globally between a limited number of connected research facilities (Mahroum 2000: 514). By moving between different facilities around the world, nanoscientists acquire prestige and recognition since they get access to new, and hopefully, more powerful networks (cf. Mahroum 2000). This intra-space mobility is determined not only by the individual researcher but also by accessible social networks inside the community which thus restrict the choice of the individual's movement.

The global character of the nanoscientific community at MC2 also becomes apparent when looking at the researchers' individual homepages. Many of the researchers have private homepages that are used to present their *curriculum vitae*, articles, and current work etc. Besides this professional information, quite a few also give their homepages a more personal touch to be used by friends and family. There may be family pictures for downloading, description of hobbies, lists of favorite writers, drawings, jokes, poems, and one scientist even published a list of his

620 CD's by artist, title and year of release. Even though there is a norm of separation between work and private life, the two are sometimes connected in the material presented on these web-pages. Combining academic *curriculum vitae* with private pictures serves the purpose of keeping up and strengthening both professional and private social networks in which colleagues, family and friends are found all over the globe. The homepages also stress the individuality of the researchers as they give the reader information about their interests and hobbies.

Nanoscientists and the global middle class

Membership of the nanoscientific community is acquired through individual occupational choices making it part of a labor identity, which is an attribute often ascribed to social class. According to Anthony Giddens (2001: 282-283) social class deals with social stratification based on occupation and wealth and is therefore not something formally inherited as people may change class through their life choices. In discussing social class I base myself primarily on Bourdieu (1979) and his discussion regarding lifestyle aspects. Different labor categories create different lifestyles, manners and taste and are given different status, which in consequence produce socially stratified classes. For Bourdieu upbringing and education set the preferences for taste in music, literature, and sport etc, thus making the concept of taste as something acquired through interaction with others. Class therefore becomes the collective transformation of individuals in identical social settings, such as upbringing, schooling and work (Bourdieu 1979: 112). Social class is however, not only a mental process for Bourdieu (1979: 190) since it also materializes physically in the body, through posture and body shape. Feeding habits, for example, influence weight. Consequently, the nanoscientists in this study, create occupational-distinct norms of behavior and taste by interacting with each other and the environment on a daily basis.

In general, social class is rarely discussed in ethnographies on scientists. A reason for this may be that researchers belong to the middle class, a class whose values have become the norm for society at large making it "naturalized" and "invisible" (Löfgren 1987, Sulkinen 1992). The middle class is also the social strata that most of the ethnographers seemingly come from which may make social class in scientific communities "invisible" even to them. An exception to this is Gusterson (1996) who in his study of nuclear physicists sees the struggle for and against nuclear weapons as a struggle between two subdivisions of the middle class which he describes as *technical* and *humanistic* respectively. The technical middle class is in a broad sense positive towards nuclear weapons while the humanistic middle class in a broad sense is against them. Both divisions are products of the university system but they differ in that the technical middle class has high cultural and economical capital compared to the humanistic middle class which has high cultural capital but low economic capital. The struggle over nuclear weapons is therefore not only a struggle over the weapons *per se*, but also a struggle over different life style values, promoting a technocratic or a humanistic society.

In accordance with Giddens (2001: 295) I see the middle class, in a broad sense, as those holding occupations and associated lifestyles that are reached by merit through education or other qualifications giving its holders greater material and social benefits than those acquired by manual labor, i.e. the working class (Giddens 2001: 293). The middle class is also more socially mobile than other classes moving socially upwards and downwards depending on life choices (Sulkinen 1992). Since social mobility is guided by personal choice individualism becomes an important part of middle class lifestyles (Lukes 1973), a trait playing an important role in understanding the nanoscientific community.

Among the researchers at MC2 the great majority share a middle class upbringing that, arguably, gives them a feeling of being socially at home in the scientific environment. The overwhelming majority of the scientists come from families in which at least one parent has a university education and more than a few also have parents who work at universities. Taking exams, doing research, writing papers, expressing oneself in scientific writing etc. are thus social phenomena that already are known to most of the researchers at MC2 before they enter the university system. Middle class parents with an academic background moreover often invest heavily, both socially and financially, in their children's education fostering new generations of academics (Wright 1997: 87). This emphasis on education is in stark contrast to various working class environments that rather foster a resistance to higher education (Mac an Ghaill 1994, McRobbie 1991, Willis 1977), making this group less likely to nurture nanoscientists.

Many of the scientists at MC2 described how technology was a family interest. Parents commonly helped their children who received good grades in natural sciences, which was necessary for subsequently being able to apply for higher education in physics. A few confessed, though, that in contrast to the good grades in natural science they had a difficult time with subjects such as philosophy and history. The preference of science subjects in school seemingly confirms the divide between a technocratic and a humanistic middle class, in which technocrats focus on natural science and humanists focus on the arts. These different academic foci in turn seem to affect the worldviews of the two groups, as the technocrats seems to emphasize technical solutions for constructing a good society while the humanists emphasize the transformation of the human spirit.

The similar social background that the scientists share contributes to form a nanoscientific community with a common lifestyle and values including dress codes and other markers of taste. The whole social environment is constructed on a code of modesty and an ideal of "not to be seen" and the majority of the researchers at MC2 do accordingly not stand out in a crowd. Many of the nanoscientists are, however, good at using computers and it is not unusual to see researchers at MC2 tinkering with them. An important marker of communality for the members of the nanoscientific community is that they generally are good at, and fond of, mathematics and physics and that they see beauty in these subjects. This liking of mathematics and physics seems to have been acquired early on in their lives which means that their interest in those subjects is not, primarily, a product of their career choice. On the contrary, the scientists rather let taste guide their careers. A number of the researchers at MC2 I talked to were upset because primary schools did not help the pupils acquire a taste for mathematics and physics. The problem today, a researcher told me, was that so few people study mathematics and physics in elementary school and that, "It is okay to say that 'mathematics is difficult', but it is not okay to say that 'Strindberg is difficult'."

In the statement above August Strindberg, the famous Swedish author, becomes a symbol for the divide in taste between humanists and technocrats. To be well versed in literature is among humanists a valued social skill while among nanoscientists skills in mathematics and physics equate to higher status. Having certain skills, such as being good in mathematics and physics, assists in combining the nanoscientists' mixture of taste, lifestyle and occupation. Extensive education, travel, long working hours and recruitment through social networks, tie the scientists at MC2 together into a web of shared everyday experiences, forming a unified lifestyle.

An important part of this unified lifestyle is civility and it is highly valued to be well-mannered and calm (cf. Shapin 1994). Civility is of course a relative notion, but compared to various male dominated working class communities which emphasize a "macho attitude" the nanoscientists are in comparison civil (cf. Bourgois 2003, Willis 1977, Wright 1997: 120). The civil ideal does not mean that people never get angry or upset, just that it is not considered proper behavior to demonstrate it publicly. During a lunch break one of the researchers came through the lunchroom door upset about EU research policy and the extra fees charged by bureaucrats on research funding. He talked loudly and waved his arms about in frustration. The conversations stopped as we all listened to the upset researcher. When he had finished, after a couple of minutes, he left but returned shortly afterwards apologizing for being upset and promising to be quiet and not to speak about politics anymore. After a short moment of silence people at the table started to laugh at his outbreak, and agreed on the angered researcher's view that there was too much tax on research funding.

On another occasion I was following three researchers who were conducting etching on a small sample they had got from another laboratory in Sweden. The sample originally came from the USA and it was rare and expensive. Being the only piece available, the researchers told me that each step in the lithograph process had to be a success. After conducting the lithograph process it was time to dry the sample with a spray which made it break into small pieces. Instead of becoming angry or upset at the failed experiment the atmosphere among the three researchers was quite jolly. When asked about it they commented that the piece had cracks in it before the experiment started and therefore it would have broken anyway, thus, there was no point in getting upset about something that would have eventually happened. This kind of reaction occurred on several occasions; people may get sad and angry when experiments fail but the norm is not to show strong negative or positive emotions publicly. Instead one should act civilly both in times of crises and in times of success.

The process of socializing researchers into "proper" behavior starts during undergraduate education. One of the researchers said that during this time the teachers constantly told them about the "scientific attitude" which meant to be careful with what one said and that what one said should be correct. A senior group leader, for example, combined rationality, logic and efficiency into a scientific attitude when he told me:

> Researchers are driven by logic. It can be frustrating with people who are driven by emotions. I get frustrated when people act irrationally which sometimes causes problems at home. Recently we were to buy a moped to our son. I thought me and my wife had agreed. The day after she wanted to take several steps backwards and discuss the matter once more, although we had an agreement from the day before. I want a chain of logic in discussions. Why should we start all over again? There is a demand for efficiency among researchers; one cannot again and again be harping on the same string.

Failed experiments taken lightly, learning to be careful with what one says and thinking logically form an intricate part of the nanoscientific community's code of behavior. Self-control and a self effacing attitude are taken to their extremes with the explicit code that governs behavior in the cleanroom laboratory, which I will develop in chapter six.

The community's norm of civility is probably part of a greater class ethos emphasizing self-discipline, orderliness and rationality, characteristics that have been attributed to the Swedish middle class (Löfgren 1987: 78, cf. Ambjörnsson 1998). The archetypes of the humble, polite and civil scientist are also traceable all the way back to the scientific revolution (Shapin 1994). Members of the British Royal Society were gentlemen, who all belonged to the male elitist gentry and among themselves they were equals. They also emphasized virtues like modesty and civility (Shapin 1994). These archetypes were then transferred to the new natural sciences, subsequently to become ideals for scientists all over the world, such as the nanoscientists at MC2.

Summary

To belong to the nanoscientific community is an active choice and the researchers bond through a shared educational history, hopes of a shared future, and a sense of belonging to a group. Inside the nanoscientific community there is a notion of separation between an intramural working sphere and an extramural private sphere meaning that researchers off-work lives are not necessarily well known among colleagues. During undergraduate days the students' time is monopolized by studies and many of them start to strengthen intramural social relations at the expense of extramural ones and over time a shared set of meanings emerge. These intramural networks are ego-centric as each individual builds up his or her own network, marking the strong emphasis on individualism inside the community.

The nanoscientific community is also experienced among its members as being global, an understanding that is reached by excluding the local civil society. The experienced globalness is reached through forming and maintaining relationships with international research groups and through self-identification as international researchers. The vast majority of researchers also come from middle class backgrounds which generate a working environment with common class based lifestyle values. This lifestyle emphasizes individualism, universalism, civility and a liking for mathematics and physics, factors that together contribute to the creation of a universal objective nanoscientist. Individualism is emphasized as each researcher creates and maintains his or her career through personal life choices; a notion which co-exists with a scientific ideal of universalism in which the objects of study are in focus stressing a self effacing of the researcher.

4. The lifeworld of the nanoscientist

Individualism and universalism constitute two central aspects in an understanding of the researchers' *lifeworlds*, i.e. the day-to-day world with which each individual interact and experience. Individualism and universalism may, at a first glance, seem contradictory but together they contribute to form the researchers' experience of science as objective and disembedded from cultural conceptions, a belief that can be traced back to the scientific revolution (Shapin 1994, 1996). Since nanoscientists move through a global arena, where as individuals they are interchangeable and where scientific results are exchanged, their conception of nanoscience as universal is strengthened. The universalism that is experienced is produced since cultural concepts are considered to be irrelevant and in this process the image of a *"raw" individual* with as little cultural connections as possible is simultaneously created. The understanding of researchers as "raw" individuals exists in parallel to the way they perceive nature, which is in the "raw" natural state unaffected by human interaction. In a sense it can be argued that the researchers objectify themselves when conducting science and ascribe inanimate attributes to animate beings. As life is an epiphenomenon derived from inanimate nature, concepts derived from life, such as culture, nationality and gender also are epiphenomena which hinder the scientists in studying nature objectively, i.e. from the stance of nature.

In accordance with the perceived "raw" individual described above, the individualism experienced by the researchers means that they presumably only valuate themselves and their peers by their skills and unique personal qualities, while collective qualities such as ethnicity and social class are found to lack importance. In this chapter the notion of the irrelevance of nationality, gender and religion to science will be examined.

The type of individuality found among the researchers at MC2 seems to be part of a grander tradition of modernity in which individuals peel off their cultural skins and create a universal sameness of humankind (Lukes 1973: 151), a notion expressed by several of the researchers at MC2. For example, I was told that individualism is a consequence of the progression of humankind at large and that "humans have been herd animals and still are herd animals, but it is something that we are changing as we become more and more individualistic." At the same time as individualism is emphasized and personal skills are the means to make a career, there is also, however, a tendency to efface the self since it is the scientific results that are placed in the centre of research and not those who produce them.

Individualism and its social implications have been analyzed by many scholars, emphasizing different aspects of the phenomena. Commonly a central theme in the conceptualization of individualism seems to be the detachment of the individual from the surrounding social and natural settings (Dumont 1986, Lukes 1973, Sahlins 1996). Lukes (1973: 125ff) emphasizes that individualism detaches humans from both natural and social restraints and that humans are therefore considered to be responsible for their own thoughts and actions as well as having a right to privacy, i.e. to think for themselves without interference from others.

The ideas of free thought, free action and privacy are linked to notions of self-development in which individuals strive to fulfill personal interests. Lukes (1971: 84) connects individualism with the middle class as it is in this social stratum that upward and downward social mobility are most likely to occur. One characteristic of the middle class is the emphasis on individual working skills as the principal means to create wealth and therefore, Lukes argues, it is among the middle class that individualism has its fiercest advocates. I agree with Lukes in his link between social class and individualism. Among the nanoscientists, who mostly come from a middle class background, there is no great adjustment to conform to a community in which individualism is embraced since it is a norm they have most likely encountered during their upbringing.

A "culture of no culture"

When asking researchers what culture signifies to them they often refer to things such as customs and religion which are extramural and exist outside of science. One of the first interviews I undertook was with a researcher from a Mediterranean country. When asked how he felt about being in Sweden, I was told that there was no difference between physics in Sweden and in his home country. Outside the department there were differences but inside it was all the same. At work everyone is serious and do their tasks, "at work one only talks about science," he concluded. Not long afterwards when I talked to a female researcher about cultural differences, she observed:

> I enjoy traveling. There are cultural differences between different countries. In natural science, on the other hand, there is only a difference in structure; how the science is organized. The content is the same all over the world. I have, for instance, worked in Germany without any cultural problems. As a researcher one is treated equally to all others, it has nothing to do with sex. All are following the same laws, the laws of physics. If you are in the same discipline one understands each other.

Conversations with other researchers confirmed the general acceptance of these views. When asked about cultural differences between researchers I got answers such as "there are no cultural differences," "people are used to the international environment when they come here," "we do not have time for that," "it is hard to know what is cultural and what is individual," "I am probably too stupid to notice any cultural differences." All these comments stress the notion that culture is something considered unnecessary inside the community, a view that is accentuated by the understanding that laboratory environments are almost identical around the world and in which global likenesses among the researchers are emphasized over cultural differences.

It is fair to say that a few of the researchers said that there were cultural differences between themselves but that they did not think too much about it. A foreign researcher told me that he had learnt much about different people since coming to Sweden. He gave me a proverb from his home country "a good word in one language can be a bad word in another language" and concluded our conversation stating that in the end you can only be yourself, emphasizing individualism over collective cultural traits.

Among the researchers there is a notion of being part of a community that ideally consists only of individuals without any particular cultural attributes that affect their scientific practice, instead of the idea of being part of a cultural collective. Culture is considered, in accordance, as being located outside the scientific community and being an aspect of humanity that should not influence science (cf. Forsyth 2001). Inside the community there are consequently only individuals who partake in a universal quest for discovering truths about nature. This denial of culture amongst researchers leads consequently to the forming of an intramural community based on "a culture of no culture" (Traweek 1988: 162). For example, two good friends, coming from countries involved in low intensive warfare against each other for the last 50 years, told me that they did not talk about the conflict or of the political and cultural differences between the two countries. "One has to see the individual" one of them declared, stressing the importance of individualism inside the scientific community while making the conflict an extramural affair not affecting their friendship.

It needs to be emphasized, however, that researchers do not think that they lack culture all together, just that it is connected to the extramural sphere and therefore of no importance to the content of science. The view of nanoscience as unaffected by culture is contrasted by the scientists' notion that research groups are organized differently around the world dependent on the extramural local cultural conditions. When discussed in relation to research groups, culture is often synonymous with nationality and it is often ascribed to "national characteristics." A scientist who had been to Korea told me that "Korean research groups are as they are [being hierarchical], because the whole society is hierarchical. The structure of the research groups reflects the society." He concluded however that culture influenced the organization of work but it does not affect the content of science. A differentiation is thus made between the organization of research, which can be culturally influenced, and the actual research which deals with nature and therefore is universal and non-cultural. This view was supported by a guest professor who elaborated on the concept of cultural differences among research groups. At the time of my conversation with him he was co-operating with a professor at MC2 and a professor in Japan whom he had met during his doctoral studies in the USA. Scientific co-operation is based on personal contacts, I was told, and "it does not work when governments try to tell you whom to co-operate with." "In research there are no cultural differences, research is research, it does not matter where you are" the guest professor continued, but then added that "in the USA people talk a lot while in Sweden people are quiet. Americans are shallow but with Swedes you get a more deep relationship." The composition of the research groups are also influenced by national perspectives according to the guest professor who observed that Japanese professors stay with the same group and university throughout their whole careers while professors in the USA constantly replace group members and move between different universities.

The notion that the organization of research groups differs due to different "nationality characteristics" is combined with the ideal of research groups as consisting of individuals whose nationality is of no importance when conducting science. According to the scientists at MC2 it is the structure of the research groups that is affected by nationality while the content of science is universal and not affected. A Chinese researcher who has been working in Sweden for many years described the difference between working in China and in Sweden. In China elementary science is stressed, the researcher argued, while in Sweden research is more problem oriented. In Sweden researchers are satisfied with not explaining all phenomena, I was told, while in China researchers want to understand the primary principles behind a phenomenon. These differences are however only differences in the organization of research and they do not affect the actual content of science, he concluded.

There seems moreover to be an essential understanding among the researchers with regard to what culture is and cultural expressions are frequently described in terms of ideal national types, i.e. "Swedes are like this" or "Chinese people are like that." When talking about culture, researchers could for example tell me that "Swedes do not talk much to each other" or that "Russians are tough which makes them good researchers." In contrast to the collectively shared attributes of national type, people inside the nanoscientific community are often described in particularistic and individualistic terms. There is accordingly a process of acculturation in which researchers go from national stereotype to individual, from outsider to insider. For example, a Swedish researcher told me jokingly how he had helped a newly arrived foreign PhD student to eat with knife and fork instead of eating with his hands, which was the norm in his home country. For the Swedish researcher there was a "non-cultured" norm of how to eat at MC2 and the foreign PhD student had to get rid of his "cultural way" of eating which was not proper behavior at the facility. The Swedish researcher also described how over time the foreign student also got rid of other cultural traits such as nodding his head sideways when complying. Over time the foreign PhD student got rid of more and more of his "cultural baggage" and became increasingly like the rest of the researchers at MC2, thus going from a cultural outsider to an acculturated insider, according to the Swedish researcher.

When examining among the foreign researchers what is implied by the "ideal Swedish type" a common understanding emerges according to which Swedes are relaxed and emphasize equality. Accordingly, to be on a first name basis is the standard for interaction between researchers at MC2, underscoring the norm of equality in the community where titles are of little importance in everyday sociality. A doctoral student from Eastern Europe described how it took a while for her to feel comfortable addressing the professor by his first name which in her country would be a sign of disrespect.

This "relaxed and egalitarian atmosphere" is not always conceived of positively. The Eastern European doctoral student referred to above told me that although it is nice with a relaxed research environment it does not push you enough to perform which is something bad with the Swedish system. "One works better under pressure," she argued. A Swedish senior researcher told me that there were hierarchies at MC2 but the lack of explicitly outspoken hierarchies made it hard for foreign researchers to grasp the departmental social stratification. In Sweden, he continued, doctoral students are more seen as colleagues which makes it important to have an explicit boss who tells people what needs to be done.

The lack of explicit hierarchies at MC2 seems to create a contrast between an egalitarian ideal and a need for efficiency. A number of the foreign scientists thought that the lack of a clear hierarchy in Sweden made research slow. An Asian researcher, for example, told me of a copper cover which in his country only took one or two days for the workshop to finish, while in Sweden it had taken a month. He told me that the reason for the long manufacturing time in Sweden was the refusal of the construction crew to work overtime and that they did not see the researcher as an authority they had to obey. This refusal of working overtime was a general problem in Sweden making scientific progression slow according to the Asian researcher.

In general, that research groups are organized according to national cultural conceptions, is seen as something negative, as the content of science is not ideally to be mixed with culture. While some researchers see the relaxed and egalitarian atmosphere as something which makes science slow, others told me how the strict hierarchies that characterized research groups abroad are bad as they hinder scientific creativity. Both these views share the same perception of culture as something that stands in the way of conducting good science. In short, a relaxed environment makes people lazy while a strict hierarchy hinders ingenuity.

In contrast to the research groups, which are often described as being constituted according to national cultural influences, the individual researcher is ideally only valued for his or her own personal skills. It was accordingly stated that it is the individuality rather than the culture of each person that is of importance and I was told that "inside the research society one is more individualistic, it is the results that count, not clothes or haircut." The emphasis of individuality also means that to be in control of oneself, to control one's own life, is something good while controlling others' lives is something bad. Religious and ethical convictions are thus seen as private individual affairs. Religious beliefs are rarely discussed and a Christian researcher told me that he had not told his colleagues about his faith since "one does not talk about such things." In a similar manner ethical conviction is a private affair. A researcher who did not want to do any military related research emphasized that this was an individual decision, saying that he could not condemn nor tell others what to do. Religion and ethics are thus considered to be of no relevance for actual science and if such notions should interfere with science it would be seen as something negative among the scientists at MC2.

Notions on gender and science

In accordance with the universalist and objectivist notion of nanoscience, gender is of no relevance. Gender and sex are conflated and seen as a mere biological condition and not as something socially constructed; a model of sex associated with the researchers' view of objectivity, i.e. of placing objects in the centre of attention. This does not imply that there is a general disinterest in the issue of gender; it is just that gender is perceived as irrelevant to the conduct of research. A female researcher, who agreed with this view, declared that she did not believe that men and women are interested in different things researchwise and that research interests were dependent on the individual and not on sex; thus, she emphasized the overriding importance of individuality for conducting research.

The male dominance, with only ten percent female researchers among the staff, is often explained by factors perceived to be extramural to the community. Some of the researchers at MC2 argue that there is a general feeling in society that technology and mathematics are "male" subjects which contributes to the reduced number of female applicants to MC2. A male researcher active in the making of recruiting policies noted that the society is not an egalitarian environment since girls are kept away from technology in a process that starts in kindergarten and compulsory schooling. He then described how Chalmers University of Technology had tried with selective measures to change the sex ratio of the undergraduate students with good results but as soon as they stopped this initiative the number of female applicants declined once more. In a similar manner, a female researcher blamed the widespread notion that natural science is boring for women as the cause for the predominantly male working environment at MC2. In society at large, she told me, it is important for females to be familiar with different operas and novels but it is not important for them to be able to fix their own video recorder. The female researcher thus expressed her frustration with regard to the common notion in society that "technological" knowledge is in some sense male while "aesthetic" knowledge is female.

The irrelevance of gender for science has been questioned by several social scientists arguing that the perception of an allegedly neutral stance of researchers is in fact a male bias (Forsyth 2001, Fox Keller 1999, Knorr-Cetina 1999, Traweek 1988). Among the analyses that depart from the perceived irrelevance of gender to science it has been argued that the denial of human agency in the construction of science coexists with an image of nature as female and scientists as male (Traweek 1988: 158), and that the perceived mono-gendered researcher seems to be more male than female (Knorr-Cetina 1999: 232). Evelyn Fox Keller (1999) gives two reasons as to why female researchers consider science to be gender neutral. Firstly, they are taught that science is neutral and that to stress differences among researchers is disruptive in a social environment in which conformity is the ideal. Female researchers, accordingly, accept the male norm as their own in order to avoid being different. Secondly, Fox Keller argues, female scientists have an interest in defending the neutral stance of science as it offers a privileged outlook of the world. If females and males were to conduct different types of research this would perceivably undermine the privileged position of natural science. This study, in contrast, focuses on the norms of the observed, to whom the irrelevance of gender is part of a greater cosmological understanding in which science is a manner to describe the world objectively.

One reason why female nanoscientists do not necessarily identify themselves as being very different from their male colleagues at MC2 is that they are already used to working with men. According to a report by Göransson (1995: 79-81): when female students start their education at Chalmers University of Technology, they have already experienced a male dominated social background and do not feel alienated since they have attended male dominated technical upper secondary schools. A female researcher reflected that she had been in male dominated school environments for a long time and that she did not know of anything else, "I have always studied with men, researched with men, always been surrounded by men." According to the report mentioned above several of the female students in technology oriented programs at Chalmers also appreciated and preferred to work with men rather than be in working environments dominated by women (Göransson 1995: 82-83, cf. Ferdos 2005, Paper D, 11-12). A preference also expressed by some of the female researchers at MC2.

Researchers at MC2 come predominantly from a social background where middle class values with an emphasis on scholarly studies are strong. The middle class values expressed by the nanoscientific community at MC2 emphasize civility and proper and decent conduct. There is, consequently, no habit at MC2 of displaying pin-up posters or sexualized cartoons nor is there among the male researchers an outspoken sexist jargon. This contrasts with studies conducted among groups of working class males (Bourgois 2003, Mac an Ghaill 1994, Willis 1977). This is not to say that sexualized jargoning never occurs, just that it is not a norm and it is generally looked down upon by the researchers at MC2 (cf. Markör 2005 for a study on sexual harassment at Chalmers University of Technology). Sexist remarks may also be seen as an indicator of individual problems rather than as a structural problem, and when we discussed the matter a female researcher underlined that if there is a problem inside the research group it has to do with the individual and not with his or her sex.

The view of gender as irrelevant to science means that nanoscience is conceived of by the scientists as un-gendered and not as monogendered. M'Charek (2005: 122) argues that there is a danger in always putting on the "gender glasses" as it leads to predefining and essentializing the sexes, thus creating the development of a blind spot for the irrelevance of gender as experienced by scientists. During a lunch conversation with a female nanoscientist I was told that she was angry at those who tried to distinguish her from her male colleagues.

> The comments that I have heard here at Chalmers are innocent. What irritates me is when people want to separate between men and women. I was angered by a gender researcher at Chalmers who argued in an article that Chalmers needs more female research areas. There are no female research areas in physics. There are no pink atoms! I do not think differently than men, all role models are men. I do not want to hear that I am different, I do not think differently…. It has for instance been said that women prefer to work in small groups rather than in large ones, but guys also want to work in small groups. However, girls are quieter in large groups, something we are taught to be. Sometimes I and some other female doctoral students talk about it, but we mostly become angry at those who try to distinguish us from the males. The individual differences are larger. I do not have a special genetic way of thinking. It is not that I think physics differently. The difference that exists when one starts the education is erased by time. As a girl one is given special treatment in a positive way, people pay attention to you…. At Chalmers one is not judgmental, it is a relaxed atmosphere. Most things are accepted. I have never felt bothered as a female of what people at Chalmers have said or done, there is a relaxed atmosphere, but I have felt bad when watching TV, some of the programs can be degrading to women.

This nanoscientist clearly expresses the common emphasis on individualism and the view of the irrelevance of gender in research. This notion of an un-gendered community is part of the norm of individualism according to which individuals should play down all distinguishing collective attributes. As there are many types of minorities in the group of individuals that constitutes the nanoscientific community, females are just one of several. A female researcher straightforwardly put it "it is unusual to have women researchers, it is not abnormal."

Notions on religion and science

In a similar manner to gender, religious beliefs are generally understood to be irrelevant to nanoscience. The dominant perspective of the community is materialistic and to the majority religion does not have anything to do with science. When I discussed religion with non-believing researchers some of them described it as a relic of an unenlightened past and, for example, I was told that religion will disappear as industrialization spreads and the people will not need it anymore.

Religion is understood to belong to the private, extramural sphere and religious matters are therefore something rarely discussed among colleagues. A religious researcher told me during a conversation that "as a scientist, one should not believe in God, but I do, I'm probably the only scientist doing it." Among the religious researchers I talked to, a common view is that God is seen as the creator of nature and natural laws and that God is therefore beyond the scope of nanoscience which deals with the understanding of nature. There are occasions, however, when religious researchers mix religion and science, such as when they pray before experimenting for success. However, the dominant materialistic perspective was still clear and neither of the praying researchers wanted their colleagues to know about it. A few actively religious researchers even asked me not to tell their colleagues about their faith which emphasized the private nature of religious belonging.

Among the researchers at MC2 there are two tendencies discernible towards religion and science. The first tendency is that faith is part of the extramural sphere and not a part of nanoscience. Religious researchers who share this perspective make their conviction a private affair separate from their role as scientists. The other tendency is primarily held by actively religious researchers who emphasize the universalistic nature of their religion which also affects the social structure of religious organizations. At Chalmers, in general, there are tendencies that student organizations focus themselves inwards on the university, not only in recruitment but also activitywise, which can be seen among some religious organizations. By excluding extramural differences the on-campus religious organizations emphasize universalism and form strong intramural ties with members from all over the world.

Since religious convictions are rarely discussed among the people at MC2, it was mostly during private conversations that a few researchers told me that they were believers, which makes an estimate of the number of religious practitioners unattainable. The researchers I talked to whom I see as actively religious belonged either to the Christian or to the Islamic faith. By “actively religious” I am referring to people who think that religion is an important part of their daily life and who attend religious gatherings such as Muslim Friday prayer or Christian Sunday services on a regular basis. There was a difference between Christians and Muslims in that the former predominantly worshiped off campus while the latter predominantly worshiped on campus. This difference affected my knowledge of the two groups as I only had opportunity to participate in the religious practices of those of the Muslim faith.

There are organized Christian groups at Chalmers but none of the Christian researchers at MC2 with whom I came into contact participated in them. The two major Christian groups, *Chalmers Christian Group* and *Chalmers International Catholic Students*, are not congregations in themselves but offer students advice on where to go for Sunday prayer off campus. In contrast, the Muslims with whom I came into contact all belonged to a Muslim student organization that conducted Friday prayer on campus. It is seemingly easier for Christians to worship off campus as Sweden is a predominantly Christian country and therefore has many Christian congregations for believers to choose from. For Muslim researchers, on the contrary, mosques are few in comparison to the number of churches and they are not so accessibly located, since they often are found in the suburbs and some of them take positions in religious issues that are not in agreement with the views of the Muslim middle class researchers.

Those religious researchers who emphasize faith as part of the extramural sphere obviously distinguish between science, which deals with facts, and God, who is seen as the creator of those facts. The cosmology of science is therefore not mixed with religious cosmology and a Christian theorist declared that to be a Christian did not influence his calculations.

Some religious researchers emphasized how their faith was universal and objective in the same sense as science and that the quest for objective knowledge became almost a religious duty. According to a Christian researcher “religion is physics, physics is about understanding the world that God has created.” This opinion was explicitly shared by a Muslim researcher who commented that "There is no conflict between religion and knowledge. In Islam one should seek knowledge. The Prophet asked people to get knowledge from China." In another discussion with a Muslim researcher I was jokingly told that according to the Koran one should read a lot and all Muslims should therefore be scientists since Islam tells you to do research.

The universalism of religion was commonly emphasized by the Muslim researchers and affected the social structure of their religious organization. As it turned out a few of my principal interlocutors happened to be active Muslims and they gladly arranged for me to accompany them to Friday prayer held on campus by the Muslim student organization. When I arrived for my first Friday prayer they had placed praying mats on the floor and a table and chair for me at the back of the room, looking over the participants. The Friday prayer started with 6 participants but people dropped in, one after another, eventually numbering 32 participants. The reason for the drop in, according to the partakers, was that Friday prayer have to fit in with the hectic schedule of the researchers. Later, when a Friday prayer had lasted for an hour, I heard a complaint from some participants saying that half-an-hour prayer is enough and that it should not be longer since people have other things to do.

It was also stressed that politics should not to be discussed in the Friday prayer, as it was considered to be divisive. The Muslim researchers I talked to promoted an Islam conceived of as a universal community, and when visiting other university campuses around the world there were similar Muslim organizations in whose prayers they participated, thus emphasizing a universal fellowship among Muslim scientists.

One aim of the Muslim student organization is to help foreign students avoid experiencing culture shock when they come to Sweden. A researcher at MC2 who helped newly arrived Muslim students described how he himself initially had problems finding food in Sweden, "where to eat without getting pork," a problem that the organization nowadays helps out with, directing students to shops that sell *halal*-butchered meat. The researcher continued by letting me understand that his problems of getting food were less problematic than if he had been a vegetarian, another lifestyle with dietary rules. "If you want to be in an international environment you must respect the differences," he concluded. The Muslim researcher saw his religion as an individual choice and as one out of several lifestyles that need to be respected in a global community. He did not, however, believe that his lifestyle needed special treatment inside the community as it was up to him to find food according to his dietary rules making his belief a private matter.

It seems that the notion of a universal Islam as found in the Muslim student organization is emphasized through disembeddedness and the exclusion of the extramural local society. The Muslim student organization, accordingly, are for university educated people with a focus on campus activities:

> The reason for Ramadan is that one should feel the suffering of the poor. During Ramadan I work more as I do not go to lunch. As a part of Ramadan we give money to the poor. This is an amount set by the Muslim student organization, 50 kronor for each person in a household. This year and last year we gave the money to a poor master's student at Chalmers who is here but lacks the money for the education. I am not that keen on giving money directly to mosques as I do not know were the money goes. They can send money to terrorist activities. Some of the people ruling mosques in this town are uneducated and very narrow minded.

The commentator above comes from an intellectual middle class upbringing and promotes a secular Islam which according to him is not found among local mosques. From the stance of the Muslim scientist it therefore becomes quite natural to conduct religious activities on campus among fellow researchers with similar social background and similar secular notions of Islam. The exclusion of the extramural local environment thus assists the Muslim researchers to reach conformity and a feeling of belonging to a global fellowship.

Writing articles

The production of scientific articles is an essential part of nanoscientific practice and it is therefore important to examine conceptions relating to writing for the understanding of the nanoscientific community. Among the scientists, however, it is research that is in focus and not the literary activity of writing papers. In spite of this, Latour and Woolgar (1986: 48-53) characterized scientists as compulsive and almost manic writers, an image that was not appreciated by the scientists of their study who rather saw their profession as aiming at the discovery of truths about nature. Within nanoscience, however, publishing is a highly ambiguous process as it is at one and the same time a process that creates self-denial, individualization and interdependence.

Nanoscientific texts do not include an "I" and humans expressing personal reflections are never present in the writing since it is just the scientific results that are reported. This self-denial of the authors inside the texts also follows from the idea of science as objective knowledge which further assists the researchers in forming an aura of objectivity and universalism for their craft (Clifford 1986).

Writing articles is a process done in collaboration with others stressing the collective but publishing articles also gives individual merit to each participating researcher. The list of authors behind an article shows, for example, all the researchers who have contributed to its writing but it also reveals the groups to which the individuals belong and the networks the authors have used when conducting their research. The first author named by an article is the person who has done most of the actual work and the last name is that of the professor.

When talking to doctoral students many of them told me that they initially looked at the first name in articles to see if they wanted to contact the author for more information. From their perspective it is the first name that signifies the greatest contributor to the knowledge input of the article. Conversely, a professor told me that he looked at the last name first as he wanted to know whose group was behind the article. To the professor the first mentioned author was not as important since doctoral students shift all the time and it is the group that has a collective stance for knowledge. This shows a difference in the understanding of how knowledge is produced depending on the individual position within the community. For doctoral students knowledge is represented by the individual author who has done the main part of the work behind the article while professors consider knowledge to be more typified by the group collectively and thus they focus on the research leader.

When talking to researchers at MC2 they give the impression that everyone in the group may suggest ideas for articles. In the end, however, it is the professor or a senior researcher who has the final say on the matter since it is they who decide which research is to be done. There are also different approaches regarding who should do the actual writing. A number of professors write articles themselves or they let experienced researchers do the writing to save time while other professors stress the importance of letting doctoral students do their own writing as this is a vital part of being a researcher. In those instances when students write articles the professors and senior researchers concentrate on proof reading.

Scientific publications are important for the individual researcher since they are the principal means for accumulating individual prestige within the community. The more published and recognized a researcher is, the easier it is to acquire economic funding to continue research which usually leads to further recognition. This process on increasing recognition Robert Merton (1973: 439-459) named the *Matthew Effect*, signifying that successful scientists get more resources leading to continued success and even more resources. Individual success, however, is dependant on the work of fellow researchers. Latour and Woolgar (1986: 192-193) use metaphors from the economic sector for describing scientific meriting and juxtapose scientific merits within scientific communities with money in the surrounding society. Consequently, *merits are exchangeable* as researchers quote each other, *merits can be shared* since articles contain several authors, *merits can be stolen* when researchers claim discoveries that are not their own, *merits can be accumulated* over time as more and more articles are produced by a single researcher, and finally, *merits can be wasted* by producing science that is not accepted by colleagues. By using the money metaphor I would propose that professors are to be depicted as "meritists" who, instead of being "capitalists" who live on the surplus wealth from workers, accumulate surplus merits from the work of doctoral students and post-docs by co-authoring articles. By having extensive networks and several people working in the group, a professor may co-author hundreds of articles emphasizing the link between individual success and collaboration with fellow researchers.

Apart from being an individualizing process the writing of articles also creates interdependence and strengthens social networks within the nanoscientific community. In a research group, I was told, one assists the colleagues in their different individual projects, and in this process one learns a bit about what the others are doing. This in turn means that when it is time to publish the results, the researchers who have helped out appear as second, third and fourth names in the articles. To be included as a co-author is something good since the more published articles means the more merits, even though to be the first name is more meriting than being the second or third one. Interdependence becomes a strategy in which everyone are the beneficiaries; the individual can increase personal prestige through more publications, it ties the research group together, and, as I was often told, it is considered to be fun to work with others. Interdependence also assists in generating uniformity within the community. If a researcher is considered odd or hard to work with, that person will suffer professionally as he or she needs to conduct most of the work alone and not benefit from colleagues' assistance and special skills. In turn, this will slow down the number of results and consequently the pace of publishing.

The interdependence of writing articles often includes the use of global networks enhancing the idea of a universal nanoscience. A paper I followed included seven authors from three groups. A theory was developed at MC2, a computer chip was manufactured based on the theory in Canada and the chip was then measured in China. The theorist at MC2 had never met the researcher in Canada who created the sample based on the theoretical work. Even though I do not know the specific relations between the people involved in this paper it is common for researchers to recommend each other to new colleagues and to make contacts at conferences in order to expand their networks, which in the end will serve to accumulate more merits.

The importance of interdependence becomes clear in publishing strategies. To illustrate the extent of cooperation we can examine the articles that formed the basis of one of the doctoral dissertations produced at MC2. I asked the researchers to describe his role in each of the eight papers that formed part of his dissertation:

First paper (9 authors, researcher first name):
The idea came from the researcher. The measurements were done by the researcher and the first draft of the paper was written by the researcher, later proofread by some of the co-authors.

Second Paper (6 authors, researcher second name):
The samples, X-ray measurements, and the idea of doing this work came from the researcher. A co-author did the microscopy. The microscopy part was written by the co-author and the x-ray part was written by the researcher with the help of a co-author. These two parts were then discussed by the authors involved to correlate the results. The first draft of the paper was written by the first author. It was then proofread by some of the other co-authors.

Third Paper (7 authors, researcher first name):
The idea to do this work came from the researcher. Some of the experiments were done by the researcher; some experiments were done by co-authors. The first draft paper was written by the researcher and proofread by some of the co-authors.

Fourth Paper (10 authors, researcher first name):
The samples were grown in France. The measurements were done by the researcher. The experiment was done with the help of a co-author. The first draft of the paper was partially written by the researcher and later proofread by some of the co-authors.

Fifth Paper (5 authors, researcher first name):
The samples were grown in France. The experiments and measurements were done by the researcher. The first draft of the paper was written by the researcher and proofread by some of the co-authors.

Sixth Paper (6 authors, researcher first name):
The samples were provided by another group at Chalmers. Some experiments were done with the help of this group and some were done by the researcher. The measurements were done by the researcher. The first draft of the paper was written by the researcher and proofread by some of the co-authors.

Seventh paper (3 authors, researcher first name):
Samples were provided by another group. Experiments and measurements were done by the researcher. The first draft of the paper was written by the researcher and proofread by some of the co-authors.

Eighth Paper (5 authors, researcher first name):
The idea to do this work came from the researcher. Post processing experiments and X-ray measurements were done by the researcher. Some of the interpretations were done in collaboration with another co-author. The first draft of the paper was written by the researcher and proofread by some of the co-authors.

The author of the dissertation had cooperated with no less than 23 fellow authors from seven different countries. If all researchers named in the thesis in turn collaborate with another 23 fellow researchers, the social network available for the author numbers over 500 people. Thus, at the same time that writing is individualizing it is also a project that depends on the involvement of several people. In this respect producing articles serves both to create individual researchers and to tie the transnational nanoscientific community together.

Summary

To sum up this chapter, universalism and individualism are central to the understanding of the researchers' lifeworlds at MC2. Both concepts aim to form a universal objective researcher by detaching the individual from the extramural local society. By making cultural traits irrelevant a "raw" individual is created with as few extramural connections as possible. The stress on individuality of the researchers means that the quality that counts for recognition is the personality of the researcher and his or her skills rather than collective qualities such as nationality, religious belief or gender, which are considered irrelevant for scientific practice. The male dominance of the working environment is, for example, often explained with reference to extramural causes while religious belonging is a private and extramural affair. This renunciation of culture leads to the forming of an intramural community based on what Traweek (1988) describes as "a culture of no culture." This view of a culturally independent nanoscience is contrasted by the understanding of research groups as being organized differently around the world dependent on local influences.

Even if there is an emphasis on individualism within the community there is also a notion of interdependence since scientific results are produced through collective efforts, which for example is seen in the process of writing articles. Texts in nanoscience only report scientific results and consequently they do not contain an "I" which creates notions of self-denial. In spite of the self-denial in scientific texts the use of the author's name is important since it is through publishing that individual careers to a large extent are made. By looking at the names of the authors who have contributed to the writing of the article it also becomes clear who the scientific collaborators were and what networks have been used. The concept of meriting through publishing has been described by metaphors borrowed from the economic sector in which scientific merits have been juxtaposed to money in extramural society. The interdependence created by producing and publishing scientific results partake in the creation of a common view of nature and in a notion of how to interact together, which are themes that are elaborated in the chapters to come.

5. Experiencing nature

From the perspective of the researchers, nature is inanimate, predictable and governed by universal laws; assumptions of nature's nature central for the nanoscientists' conception of science as objective. This does not imply, however, a strict deterministic worldview as the researchers often describe nature from a "bottom-up" perspective which means that the world of atoms derives its effects from the sub-atom world of quantum physics. The researchers' view of nature is further influenced by the notion that nanoscience is primarily about the domestication and control of nature rather than about discovering new fundamental facts of nature. For the researchers, dealing with a domesticated inanimate nature is a personal affair in which curiosity and the appreciation of the aesthetic properties of nature are factors that influence their choice of becoming scientists.

According to many of the researchers at MC2 there are two different kinds of physics which are used to describe nature. There is *classical physics*, with determinism and solid matter, which is applicable down to the point of atoms and there is *quantum physics*, with uncertainty and no solid matter, applicable to sub-atomic particles. The different levels of physics were described to me in the following manner:

> Quantum physics is interesting, it is the truest model that we have of matter. I separate between microphysics [quantum physics] and macrophysics [classical physics]. Microphysics studies things that are small, mostly sub-atomic particles. Macrophysics is more about statistics, it is the next regime over microphysics, it adds the effects of microphysics. Macrophysics is spread out microphysics and is the sum of quantum phenomena. It is as if individuals cannot speak, but only groups… Between micro- and macrophysics is mesoscopic physics. It is here the nanometer level is placed.

In general, when doing research, the nanoscientists see nature from a bottom-up perspective in which quantum physics is the foundation. This bottom-up perspective also means that life is seen as an epiphenomena emanating from the inanimate world of atoms and below. Since the nanoworld is placed in the interface between classical and quantum physics both types of physics are applicable in the nanoworld. An atom may be described in the terms of classical physics as a particle and at other times as a quantum wave function. Nanoresearchers see no contradiction between classical and quantum physics, to them they are just two models that describe nature on different levels. The reason for not using quantum physics on higher levels is that quantum calculations are so complex in comparison to calculations of classical physics, and when choosing models there is a principle of simplicity which says that if one may choose between two models that both serve, one should choose the simplest.

Even though researchers at MC2 see nanoscience as a logical continuance of existing science, the way nature is manipulated at the nanometer level differs compared to how it is done at the micrometer level. Firstly, by manipulating single atoms and molecules nanoresearchers have reached a kind of lowest level as they handle the smallest stable building blocks of nature. The nanoworld is in this sense a world of next to nothing, and as described by a researcher "it seems as if the nanolevel is some kind of limit for electronics. It seems to be a stop, there cannot be any picoelectronics [1 picometer equals 1/1000 nm] as you then are down on the level of subatomic particles." Secondly, on the nanometer level a world opens up that is not behaving in the same way that conventional common sense leads us to expect. Single atoms, for example, have different properties compared to when they appear in bulk. Quantum effects start to show on the scale of a few nanometers which means that particles start to behave as if they were waves rather than solid matter. Atoms, for instance, may change each others position due to quantum influences without them being in contact, which is in contradiction to everyday experience. In a similar manner color is contradictory to everyday experience when going down in level as visible light has a bandwidth of 400-800 nm, which means the nanoworld is a world without colors. I was told although that it is still possible for trained scientists to see differences between dissimilar surfaces on samples even below the limit of colors. For the researchers colors are just wavelengths of photons and human vision is consequently not needed when studying them; researchers who are color-blind work without problems with photons.

To work on the nanometer level therefore means to experience a world with phenomena that are contradictory to common sense and everyday language usage since that has emerged to deal with experiences of larger levels of existence than the nanoworld. As a result, researchers need to create terminologies appropriate to deal with these new types of experiences. Among the scientists at MC2 common words may as a consequence have a double meaning which is not always easily detectable for outsiders. An atom can, for example, be described as "endless." This characterization does not imply that the atom is literally conceived as endless, just that it is described by a wave function in quantum physics and, theoretically, this wave is endless, because before you look for the atom it can be anywhere. The double meaning of words is also seen in the use of anthropomorphic expressions when describing the nanoworld. Atoms are referred to as "lazy," and nature may be ascribed a will to preserve energy etc. This does not mean that the researchers believe inanimate nature to be alive or to have animated attributes, just that common language, which is sometimes anthropomorphic, is the easiest way to communicate in everyday situations.

Curiosity

Few social scientists have shown an interest in examining the significance of curiosity and its role in social life and, of course, even less as a driving force amongst researchers. One of the few exceptions is Bourdieu (1990) who discusses the importance of playfulness in science which he connects to academic freedom. Curiosity and playfulness, he argues, are important parts of a *scholastic point of view*, the specific vision found within the academic space. This specific academic space positions researchers in an environment in which they are allowed to pursue scientific quests with no concern for the outside world. Science, in this sense, is similar to a child's game since the researchers are "paid to play seriously" and allowed to take the silly seriously. To Bourdieu (1990: 381) curiosity is thus closely connected to academic freedom and the ability to resolve problems for personal pleasure, a view explicitly articulated by several of the researchers at MC2. I was told, for example, that "the ideal image of a serious scientist is someone who does what they want to do," meaning that science is best taken care of by scientists who are in control of their own research.

For the researchers at MC2 curiosity is a driving force for conducting research and might best be described as a passion for understanding the fundamental structure of two separate issues, nature and technology. Some of the people described how they as children were curious as to how things worked; building and taking things apart. Others described how they during adolescence started to be curious about the construction of the world. For a few, curiosity was not important when choosing undergraduate studies in physics, instead they mentioned factors such as they wanted a challenge, choosing a subject that is considered tough, or that they liked mathematics. For them curiosity became a factor later for choosing a career in science, when it was time to decide between graduate studies or a career in industry.

Even if the moment when curiosity begins to develop differs, there is a common agreement that it as a driving force is an important part of being a nanoscientist. "To become a nanoscientist you need curiosity and stubbornness, especially curiosity, to want to know things," a researcher told me. Curiosity was even sometimes described in terms of as an obsession. A theorist spoke of the "problem solving drug," meaning that calculus can be addictive and that a special feeling of satisfaction was connected with solving mathematical problems. According to one of the researchers, engineering is fascinating as it is about understanding and creating things. During his twenties the researcher played in a jazz band and he compared playing jazz with research since both deal with improvisation and that it is possible to become completely absorbed by both activities. The curiosity that is found among the researchers is thus connected to improvisation and creativity. Curiosity seems to function as the driving force to construct and examine things in new ways, sometimes in a playful manner as described by Bourdieu (1990).

Since the ability to manipulate objects on the nanometer level is fairly recent, nanoscience is sometimes described as the last frontier. One of the researchers described his curiosity of exploring the unknown in a colorful way:

> Physics is the last frontier. In the old days explorers traveled to foreign countries to name islands and mountains. This is not possible anymore since all mountains and islands are discovered. Today it is physics where particles and formulas are named after their discoverers, like Planck's constant. Physics is like the old Wild West, a land you still can explore.

The idea that the nanoworld may be seen as a last frontier ready for exploration can be linked to rewards and prizes in science which are awarded to breakthroughs. There is, consequently, a strong drive among researchers to be "the first" and to put his or her name on animals, diseases, formulas, technology etc (Douglas 1986: 75-77). The analogy between nanoscience and the Wild West is also interesting, as the Wild West was not about discovering new territory but more about "taming the wild;" thus domesticating nature can be seen in a similar manner to nanoscience's ambition to develop nano-engineering.

According to some of the researchers at MC2 the importance of curiosity is not of equal significance within the different disciplines of science; arguing that physics is the subject that best satisfies curiosity. A researcher told me that physics is fun because it is regular and that you can invent things, aspects that he said were lacking in chemistry and biology. Chemistry lacks rules and is more of "catalogue knowledge" than dealing with the fundamental laws of nature, he said, while in biology one does not invent and construct things. The researcher argued that physics and nanoscience satisfy his curiosity better than chemistry and biology on two accounts. First because he is curious as to how one can form matter into machines, something that is lacking in chemistry and biology; and secondly, because nanoscientists deal with matter on a more fundamental level than chemistry and biology, which respectively mostly deal with molecules and living matter which derive their effects from the world of atoms. To deal with those fundamental aspects of nature are considered to be more satisfying to curiosity than to deal with nature on a larger and more complex level.

Although curiosity is a driving force among researchers at MC2, their appreciation of this drive is ambiguous since curiosity deals with feelings such as improvisation and creativity which are sometimes in opposition to the scientific ideal of experimenting in a systematic and rational manner. Individual curiosity is, for example, limited by funding agencies which only give money to specific areas of research that are considered interesting by the donors. This became clear for me on the first day of my fieldwork and the first note in my field diary is about a poster on a bulletin board which read "A physical theory must possess mathematical beauty," on which someone had placed a post-it note stating "& attract funding." The view proclaimed by the anonymous post-it writer was common among scientists at MC2. A researcher who was told by a colleague that they could be happy because they were allowed to do what they wanted, replied "at least such things that we get research grants for," thereby, underlining the restrictions for conducting free research set up by funding agencies.

Regardless of the long working hours needed for realizing the conventional projects, several researchers conducted additional research in their spare time as a way to satisfy their personal curiosity. During the time of my fieldwork there was one researcher who was interested in solar cells, a research field with almost no funding and another who was curious about cosmos and theory of gravitation, another field with little funding. Both of them were forced to engage in research in the more financially lucrative field of computers and semi-conductors.

As a driving force for conducting science, curiosity is regarded as selfish since it gives the researcher a private pleasure of experimenting. This personal side contrasts with the collective utilitarian aims of science that are often expressed in the extramural sphere. Thus there are two different stories of how science advances; one intramural story in which researchers are driven by personal curiosity and one extramural story in which utilitarian aims are the driving forces of science.

Experiencing inanimate nature

The idea of nature being inanimate is part of a long tradition found in Western history of thought. According to Marshall Sahlins (1996: 411) the early Judeo-Christians disenchanted nature, making it ready for human exploitation in the centuries to come. During the scientific revolution, nature's inanimateness was in focus and the mechanization and depersonalization of nature became important aspects for the new natural science, notions still valid among today's scientists (Shapin 1996).

Nature as experienced by the researchers at MC2 is not only inanimate it is also a processed version of nature as found outside the laboratory. The laboratory version of nature deals with compounds of matter in their raw unpolluted form rarely found in the outside world. The laboratory nature is thus the intramural version of how nature ideally should be, in contrast to extramural nature in which compounds constantly mix with each other.

It was explained to me that since the nanoworld is inanimate it is more predictable than more complex levels of existence that contain life, even though life emanates from the world of atoms. Biological systems have more parameters than systems found on the nanometer level that contain only inanimate matter. In accordance scientists at MC2 conceive of two different levels of complexity. There is *the level of life* characterized by unpredictability that follows from the complexity of animation. The smallest living object is the cell, signaling the starting point of the level of life, which is at least 1.000 nm in size. Animation means a free will and animated creatures are therefore less predictable than inanimate objects. Secondly, there is *the quantum level* in which unpredictability follows from the complexity of the instable nature of sub-atomic particles. These quantum phenomena start to affect matter that is a few nanometers in size.

In between the level of animate life and the level of quantum effects is the nanoworld, interconnected and affected by both levels of complexity. Phenomena or events at the level of life may ruin experiments as cells and other residues from animate beings, especially humans, may pollute experiments. To control and reduce the influence of the level of life, cleanroom laboratories must be used. Quantum phenomena affect experiments negatively by, for example, changing an atom's position in a random manner. To reduce the influence of quantum phenomena, nanoscientists freeze atoms to a few degrees above absolute zero to make them inert or reduce the number of unwanted particles through the use of a vacuum. Nanoscience is thus partly a struggle to minimize the negative influence of both the levels of life and of quantum effects in an effort to keep the nanoworld as simple and predictable as possible.

Going down in size towards the nanometer level and beyond, also means to deal with phenomena that in certain respects challenge the everyday understanding of the world; a theme touched upon in books on physics. Krister Renard (1995: 32-34) in his book on physics, for example, maintains that our sensory experiences are *subjective*, *instable* and *qualitative* while science, in contrast, should be *objective*, *stable* and *quantitative*. Another author warns against relying on intuition saying that intuition is no more than thought habits and since "…. those habits developed as a result of limited experience, their appropriateness to phenomena lying outside that range of experience is suspect, at the least" (Rosen 1995: 95). The same author subsequently warns against the danger of researchers distorting phenomena by not making objective observations (Rosen 1995: 173). This view of humans as distorting our knowledge of inanimate nature is also found among several nanoscientists, as I was once told by a senior researcher "we are so limited as humans that we maybe never will understand everything." Since sensory experiences are not to be trusted while doing nanoscience there is a need to substitute the limited human capacity of observation in order to be able to make adequate and coherent observations of nature. In nanoscience this is accomplished with the help of technical means and the importance of technology is therefore fundamental for the discipline. To see nature as inanimate and human sensory experience as fallible when experimenting also influences the scientists' perspective on life, which is basically regarded as an epiphenomenon of inanimate nature. A researcher once said that the way we think is based on the physics of atoms and molecules, "we are physics" he proclaimed. From his point of view, it was just the level of complexity that makes humans more unpredictable than single atoms.

When reducing life forms in scale, all living beings become more and more similar, consisting principally of carbon atoms and according to physicist Richard Jones (2004: 6) humans consist of matter and mechanisms developed and optimized at the nanometer level. The perspective of humans as atomic beings is transferred to students. In an undergraduate class on nanoscience describing different approaches of nanoscale construction, the teacher told the students that humans were self-organized molecular systems and that nature used a bottom-up approach for constructing them. The same class was told by another teacher that feelings are ultimately chemistry, although hard to study.

The conception of the nanoworld as inanimate and below the level of life means that the researchers conceive of their science to be ethically unproblematical. Some of the researchers at MC2 told me that they were against experiments on animals, but since they experimented on inanimate matter their science was not affected by such ethical issues. A physicist, whose research could be used in analyzing DNA, told me that he did not know if it was ethically good or bad to work with DNA since he had not received any directives regarding research ethics. He was just constructing a device that could be used for medical experiments and he did not participate in the experiments himself. According to Rosalyn W. Berne (2006: 77) this lack of directives regarding research ethics seems to be caused by the lack of a clear moral leadership regarding nanoscience, since nanotechnology is not ethically supervised nor controlled by governments in a similar manner as research on genes, animals, radioactive materials etc.

For the researchers at MC2 nature at the nanometer level is presumably seen as "next to nothing." Nature in the laboratory is a processed version in which unwanted matter and parameters are removed or reduced to a minimum. In a simile, nanoscience can be seen as the narrow tube in a time glass; at one end is the level of life causing complexity through animation and at the other end is the quantum level causing complexity through the instable nature of sub-atomic particles. In between is the nanoworld influenced by both the level of life and the quantum level. The nanoworld is the last level of stable matter, offering the least complexity, and accordingly becomes the last stage before the quantum world. As the nanoworld is the last level of stable matter it also becomes the starting point for life and, from the researchers' perspective, creates a view of humans as atomic beings.

The aesthetics of symmetry

The beauty in physics, as described by researchers at MC2, can be summed up as the simplicity and regularity of inanimate nature or, in terms of physics, as the beauty of symmetry. Reductionism in physics serves to simplify complexities to their elementary parts while symmetry is defined as the ability to remain unaffected by changes (Rosen 1995: 2). In physics the term "symmetry" corresponds to something rather different compared to the laypersons understanding of the word which usually is used to describe things that possess balanced proportions. In physics the concepts of reductionism, symmetry and beauty are interwoven as the employment of reductionism aims to help discover symmetries and symmetries are described as beautiful (Weyl 1952: 3). According to some physicists beauty is even synonymous with symmetry (Zee 1986: 13). In short, nature is understood to follow a small number of natural laws that are valid all over the universe. These laws are symmetrical and immune to change; the more general the laws are the more symmetrical they become and as a consequence the more beautiful they turn out to be.

Reductionism is at the core of natural science and it can be argued that the history of modern science, at least since the time of Francis Bacon, is a pursuit for finding the simplest explanation of a phenomenon. Several of the researchers at MC2 claimed that what attracted them towards pursuing a career in nanoscience was a curiosity to learn more about the fundamental laws of nature and the simple models created thereof. As these fundamental laws of nature are difficult to explore on higher levels due to increased complexity, the nanolevel becomes an attractive choice when deciding which branch of science to pursue.

Symmetry is in science something more than just an aspect of nature. On a more general level the ideal of symmetry assists physicists to choose between different theories in seemingly three associated forms: *simplicity*, *generality*, and *beauty* (Renard 1995: 25). A general theory with few variables is simpler than having several complex theories. From a practical point of view, there is also no point in learning a more complicated theory than necessary and it is also practical to limit the number of theories. Accordingly, it is practical for the researchers to choose the simplest theory that serves to explain most cases, which is the most symmetrical theory. At times researchers rationalize why nature is symmetrical in structure by referring to it as "lazy" whereby they imply an innate ability of nature to resist change. A nanoscientist told me jokingly that "…the goal of each molecule is to spend as little energy as possible, just as humans. It is nicer to sit on a couch than to walk" he said, implying that simplicity and regularity are the most energy preserving ways of existence. These anthropomorphic descriptions are not suggesting an agency of nature, as might be assumed, but are instead results of an anthropomorphic "common language," a subject elaborated on in the next chapter. To summarize, nature preserves energy in two ways: through simplicity as simple forms use less energy than complex forms, and through symmetry as changes in structure drain energy. The beauty found in simplicity and generality combined into the form of symmetry is thus the "essence" of beauty of inanimate nature.

Even though symmetry is an aesthetic ideal among the researchers at MC2 nanoscience mostly deals with asymmetries. It is the imperfections that make materials useful for manipulation as symmetrical structures resist change and therefore they do not respond to external manipulation; making symmetrical structures quite useless for construction. By manipulating matter one also adds asymmetry to it. Thus the perceived aesthetic of symmetry professed by the researchers at MC2 is not linked to their scientific practice, as they mostly deal with asymmetric materials. Accordingly, none of the nanoscientists at MC2 described the atoms, molecules or computer chips that they were working on as beautiful since the experience of beauty lies in the admiration of the correct, eternal and simple aspects of nature. A researcher summed up this attitude by simply saying that "nature takes the simplest form which is also the most beautiful."

In everyday research the scientists at MC2 see the close link between symmetry, beauty and mathematics in the ability to predict nature by simple and general formulas. As a result the notions of simplicity, generality and beauty guide the researchers in making scientific judgments, such as separating true and false formulas. During a conversation with a couple of students a professor explained that symmetry is fundamental to physics as it creates a deeper understanding of nature. Symmetry signifies regularity and predictability which can be expressed in mathematics and mathematics is what rules the world, we were told. A good mathematical theory is therefore simple and predictable as it reflects the simplicity and predictability of nature. Another researcher described the beauty of mathematics in the following manner:

> It takes a mathematician to see the beauty in mathematics. An equation that is simple and that can predict the future is elegant. A formula can give you a wow-experience!... A beautiful solution does not contain too much mess, it should be simple. A teacher once used the word filth when too many formulas were used together. To see the beauty in mathematics is an experience.

The beauty of mathematics is only meaningful for those who possess the appropriate cultural code to understand it, dividing people between those who can see its beauty and those who cannot. The understanding of mathematics thus serves as a kind of division between scientists at MC2 and laypersons. According to George Lakoff and Rafael E. Núñez (2000) among mathematicians there exists a myth which they call *the romance of mathematics*. It is a myth, they say, with strong supporters both among mathematicians and non-mathematicians. Notions associated with the romance of mathematics suggest that:

> * Mathematics describes the universe objectively
> * Mathematics is irrelevant to culture
> * Mathematics is the ultimate science
> * Mathematics is the apex of rationality and human intellect
>
> (Lakoff & Núñez 2000: 339-340, 355).

The notions ascribed to the romance of mathematics by Lakoff and Núñez were described to me by several of the researchers at MC2, especially by those who were theorists and who work directly with mathematical models. When asked why mathematics is beautiful a researcher told me the following:

> It is a hard question to answer, it is a feeling. Mathematics is not just science, it is a way of thinking. To be accurate, do you know for sure or do you just believe it to be in a certain way? Mathematics is a closed system with its own rules. Formulas that are not beautiful are wrong. Accurate results, simplicity and sharp-wittedness are beautiful. Beauty of regularity, the thinking style of clarity, honesty and balance, that is beautiful. I feel myself like a painter. Many experience mathematics as made to torture engineers, that mathematics is cold. Mathematics creates models that lead to better understanding, the model serves as a tool, and if it's not good you throw it away. Models do not necessarily last forever, they live for a while. For some physicists formulas are God, which is wrong. What mathematicians do is to improve on the models, just like a painter does.

By suggesting that mathematics is a closed system it is seen as independent of extramural culture and cannot be manipulated by humans; a correct result is always correct. For the scientist, mathematics is not only a science it is a way of thinking. Mathematics deals with accurate knowledge which is reached by sharp-wittedness and clarity making it a discipline that requires a rational mind. That the researcher above sees mathematics as a tool for improvement of the models for predicting nature signifies that he sees it as an applied science. This opinion is shared with the vast majority of the researchers at MC2 who are experimentalists and deal with nature. To these people mathematics is used for the specific purpose of creating models of reality.

The nanoscientists' experienced beauty of nature seems to go a long way back in Western history of thought. Aristotle described the chief aspects of beauty as order, symmetry and definiteness (Synnott 1993: 80). However, in everyday language beauty is also connected to ethics and there are moral aspects of beauty and ugliness. The beautiful is good and true while the ugly is supposedly bad and wrong (cf. Synnott 1993: 94); an idea of beauty also found in the nanoscientists' conception of nature. Formulas are beautiful because they describe nature in a simple and truthful way while a simple but untrue formula is not beautiful since it is wrong. Beauty is consequently linked to describing nature in a truthful way, providing us with a dichotomy between beauty-truth on the one side and ugliness-untruth on the other. This does not imply, however, that a beautiful formula is believed to last forever as a more simple, prettier, and more efficient formula might replace the previous one as science advances.

The everyday domestication of nature

Domestication is conventionally associated with economics in which humans tame and transform nature in contrast to hunting and gathering economics in which humans rely on undomesticated life forms for their support. According to Ingold (2000: 61ff) the principal reason for domestication is the increased control of resources that comes with manipulating nature.

In a similar manner, according to Detlev Nothnagel (1996), there are two ways to approach nature in physics; one approach of *hunting* and one approach of *domestication*. "Hunting" in this instance stands for a human-nature relation based on discovery while "domestication" stands for a human-nature relation based on control. High-energy physics, tracking and crushing sub-atomic particles in large accelerators are examples of hunting, while in nanoscience, I would argue, the aim of controlling particles for construction is an example of domestication. The nanoscientists' domestication of nature takes place in the closed spaces of cleanroom laboratories in which foreign and polluting elements are reduced as much as possible with the purpose of finding ways to control the smallest stable building blocks of nature, atoms and molecules.

The difference between hunting and domesticating nature can also be seen in the kind of mediating tools that are used. Ingold (2000: 72-73) in his work on hunters and pastoralists, argues that hunting is a relationship based on trust as the prey sacrifices itself to the hunters, while domestication is a relationship of domination in which pastoralists have absolute power over their herds. These two types of relationship influence the types of tools used: hunters use bows and spears for killing the prey while pastoralists use whips and other tools to keep the animals of the herd in place. Ingold thus argues that tools used for domestication are for control, designed to restrict momentum, while those used for hunting are for trust, as the prey sacrifices itself to the hunter (Ingold 2000: 73).

Even though the hunting-domestication model as presented by Ingold cannot be transferred directly into different areas of physics, I would propose that high-energy physicists use what would correspond to hunting tools while nanoscientists use tools for domestication. In the search to reveal new sub-atomic particles high-energy physics uses large accelerators to crush matter to discover its content. In contrast, nanoscientists control matter through lithographs and ovens for making nanometer-scale artifacts. The notion of domestication in nanoscience is made explicit in an animated information DVD from the European Commission (2003) in which the atoms resent the idea of being split, thus favoring nanoscience in which they are used for construction. The difference in technology between "hunters" and "domesticators" may also explain why different kinds of physicists experience nature differently; among high-energy physicists the language with which they express their experiences seems to be influenced by hunting metaphors. The process of discovery is referred to as "hunting" (Nothnagel 1996: 263), the acronym SPEAR refers to an accelerator (Traweek 1988), and getting rid of background noise is referred to as "killing the background" (Knorr-Cetina 1999: 124). In contrast, nanoscientists lack such hunting metaphors; instead they use some domestication terms such as "controlling," "placing," and "growing" to describe the process of producing carbon nanotubes. The researchers at MC2 also seem to share a strong image of machines as inanimate and accordingly they do not anthropomorphize machines to the same extent as high-enery physicists (cf. Traweek 1988, Knorr-Cetina 1999). It is the tools' inanimate character that ensures their objectivity; a necessary requirement for the researchers to achieve accurate results. To anthropomorphize these tools of the trade would thus weaken their inanimate character.

Basically, the researchers told me, there are two methods of domesticating the nanoworld. The *top-down method* manipulates matter

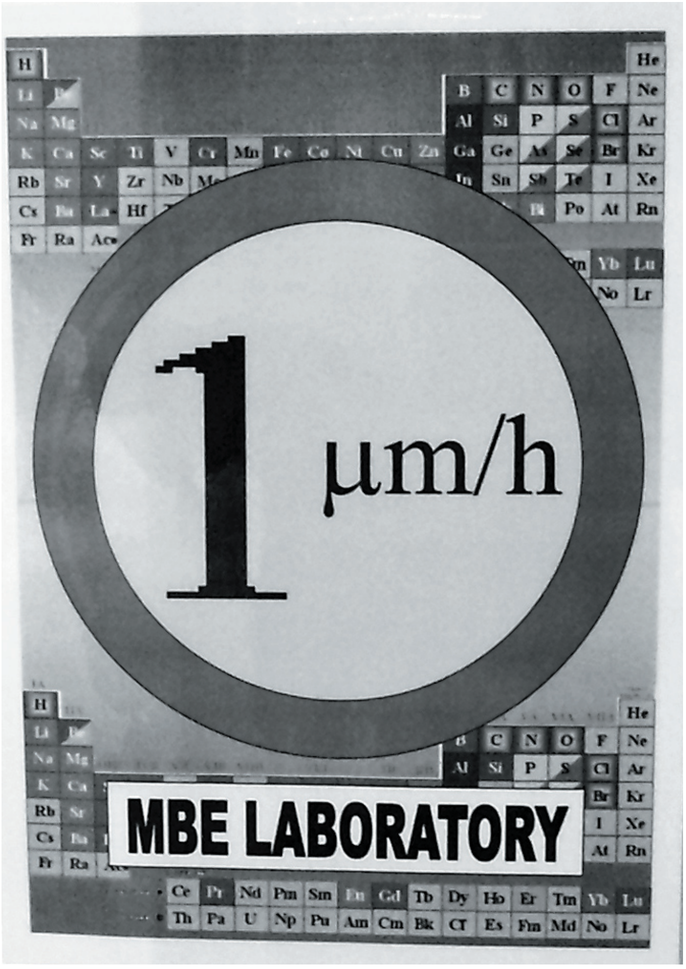


Figure 3. "Maximum speed one micrometer per hour," a joke regarding the trade-off between speed and accuracy.

on the nanometer level through machines from higher levels, such as lithographs, while the *bottom-up method* uses chemical processes to create structures on the nanometer level, such as producing carbon nanotubes. The two methods have advantages and drawbacks.

To work top-down with lithography means to trade resolution for speed. The smaller the pattern to be etched, the longer it takes. Etching on the micrometer level can take seconds while etching on the nanometer level can take hours. Researchers thus described how they are forced to compromise between the time taken to make a chip and the size of the etchings. A related problem is also sensitivity of the etching process, as the machines used have to be set exactly.

In contrast, to work bottom-up constructing carbon nanotubes means to be at the mercy of nature. The nanotubes consist of carbon atoms rolled up into a tubular net and, depending on the structure of the nanotube, different properties are acquired. Nanotubes are produced in burners in a rather imprecise manner. The process is referred to as "growing" since the carbon atoms fix themselves to each other in a manner said to be similar to the growth of a tree. The problem with growing nanotubes is to produce them in accordance to the researchers' wishes. Several variables such as temperature, moisture and pressure etc, influence the outcome which makes them hard to construct according to a preconceived plan. A researcher working on carbon nanotubes expressed a feeling of not being in charge when he said "when we grow nanotubes it is nature that controls us and you just stand beside and watch," meaning that nature does the actual growing while the researchers only try to influence the parameters preceding the actual growth.

The advantage of the top-down method compared to the bottom-up method is greater control over matter but the disadvantage is that it is time-consuming. The bottom-up method, on the other hand, is often faster. In the top-down method nature is controlled directly by humans through the use of force, while the bottom-up method signifies that researchers try to control factors preceding the actual construction, such as heat and pressure, letting nature do the actual forming of matter. Choosing a method is often a balance between accuracy, speed of research and cost. The two methods also require different types of skill. Those who are good at constructing carbon nanotubes do not necessarily have the skills required for etching computer chips and *vice versa*.

As Ingold (2000: 61ff) correctly argues the principal reason for domestication is the increased control that comes with manipulating nature compared to just observing and dismembering it. Control is not the focus of all branches of physics as some branches, such as high-energy physics, focus on dismembering nature. The nanometer world is already discovered and what is left for the researchers is the control of it; a manipulation which became possible when new technology opened up the miniscule nanometer scale for construction. The focus on the control of nature in nanoscience goes further than just including atoms and molecules as it is also humans that are in need of control, as will be further examined in the next chapter.

Summary

To the researchers at MC2 nature is seen as inanimate and following universal natural laws which lead to a conceptualization and experience of science as being objective. Their worldview is not strictly deterministic, however, as they describe nature from a "bottom-up" quantum perspective which means that the world of atoms derives many of its effects from the sub-atom world. The bottom-up perspective is also applied to their view of life which emanates from the world of atoms and below. There seems to be two different kinds of physics used for describing nature; classical physics with solid matter and determinism applicable down to the realm of atoms, and quantum physics with no solid matter and uncertainty applicable on sub-atomic particles. The nanoworld is situated in the interface between the two and this in-between relation is affected by both classical and quantum physics.

A common reason for the researchers to conduct science is curiosity which in this instance is an individual passion for understanding the fundamental structure of two separate issues, nature and technology. Also an aesthetic property of nature influences the scientists when conducting research. The aesthetics of nature are principally linked to simplicity and regularity as innate properties of the universe; properties united in the concept of symmetry. Natural laws are symmetrical, i.e. immune to change, as they are general. Simplicity and regularity are for the nanoresearchers best described in mathematical and physical formulas which quantify and generalize nature, meaning that such formulas are conceived of as beautiful.

In physics there are two different approaches to gathering information; one approach is that of "hunting" that aims at discovering new particles, and one approach is that of "domestication" that aims at controlling particles. Of these two approaches nanoscience employs the latter. This means that the tools used by the scientists at MC2 to manipulate the inanimate nanoworld are tools of control. This is clearly illustrated by the cleanroom technoscape in which external factors ideally are controlled. Going down in size also means dealing with phenomena that apparently contradict everyday experience and researchers therefore need machines as mediators to experience the nanoworld. These machines become the guarantee for stable and coherent observations of nature and are essential for the researchers' trust in producing objective science, as will be further described in the next chapter.

6. The cleanroom and its technoscape

Because nanoscience at MC2 is mostly experimental the cleanroom quite naturally becomes the heart of the department, and without it, it would be impossible to conduct the research done there today. It is therefore no surprise that when reporters and politicians visit MC2 they are, as a rule, taken on a tour looking into the cleanroom. At technology trade fairs, such as the yearly *Hannover Messe* and the *Electronics Trade Fair in Gothenburg*, it is likewise pictures of the cleanroom that cover MC2's exhibition stand. Among physics students the fascination with the laboratory is widespread. The students' interest in the cleanroom became clear to me when I followed an undergraduate course in nanoscience. The fact that I was an anthropologist did not draw much attention but during a break I happened to mention my cleanroom clearance and suddenly I received many questions about my experience in the laboratory. Even among some of the people working at MC2 there is a certain mystique surrounding the cleanroom, a mystique that fades, however, with increased familiarity.

From a technological perspective cleanrooms can be seen as a means to safeguard and guarantee the continued development of modern high technology. During my fieldwork I encountered two stories as to why cleanrooms were created. According to a manual used by the cleanroom staff, cleanroom engineering has its origins in post World War Two technology (Månsson 1992: 8). During this time nuclear technology and computers developed at a fast pace using smaller and smaller parts, which in turn became more and more sensitive to pollution. These pre-cleanroom technologies failed; planes crashed and a satellite went off course, due to pollution (Månsson 1992: 12). Another story was presented by a teacher introducing nanoscience to first year physics students who told them that cleanroom technology was a legacy from nuclear weapons research in the USA. According to this version, the military constructed cleanrooms early on due to the pollution sensitivity and radioactivity associated with constructing nuclear weapons. When microtechnology subsequently became a reality there were no large financial risks as the significant investment in cleanroom technology had already been covered by the military. According to the teacher, a reason for using cleanrooms in microtechnology was that silicon, used to manufacture computer chips, easily gets polluted and then acquires other properties than pure silicon.

Irrespective of the origin, the central issue is that cleanrooms were constructed to save technology from failure due to pollution. Leif Månsson's (1992) book referred to above is even named *The invisible enemy of high technology* [Högteknologins osynliga fiende].

The principal difference between cleanrooms and more ordinary laboratories consists in the number of particles allowed in the air. When moving on the nanolevel, microscopic dust particles are gigantic in comparison to whatever you work on, and they can easily ruin experiments, making it important to control the number of particles in the air. It can therefore be argued that cleanrooms basically are facilities that reduce pollution.

Mary Douglas (1994: 36) in her seminal work on pollution defines the concept as "…matter out of place," placing pollution within a context of religious symbolic classification. She argues that modern Western notions of pollution differ in two distinct ways from those of non-Westerners. Firstly, the Western notion is not related to religion but has principally to do with hygiene and aesthetics and, secondly, our understanding of pollution is based on scientific knowledge of organisms. Pollution in cleanrooms is elements that interfere negatively with experiments, not only including matter in the strict sense, but also acoustics and other vibrations. The notion of pollution in cleanrooms is thus based on the researchers' scientific understanding of nature. Therefore, what is polluting in one part of the cleanroom is not necessarily polluting in another part as dirt in cleanrooms is always relative to the context of the experiments; that is different experiments have different requirements as to what is negative interference (Mody 2001: 17).

The construction of the cleanroom technoscape and the associated behavior is also influenced by nature. Research at the nanometer level has to be done in a clean environment in which humans need to cover themselves to protect the surroundings. Nanoresearch is, thus, a creation of an intricate combination of conditions of nature and humans' will to manipulate matter.

For the researchers at MC2 the cleanroom is a technoscape, a human constructed landscape based on technology, in which humans interact with nature. As with all landscapes the cleanroom technoscape is interpreted differently depending on the perspective of the beholder (cf. Meløe 1988). To an untrained eye the cleanroom is a random collection of complicated machines spread out in a room, while for the nanoscientists the machines are placed according to a plan: machines that vibrate are placed in one part of the room while light sensitive experiments are conducted in an area where ordinary light is filtered. As with most landscapes, the technoscape of the cleanroom is experienced multisensorally. Being in the cleanroom is therefore an affair involving sound, touch, smell and vision (Mody 2005). The shared everyday experience of being in and around the cleanroom together with other everyday activities such as living in the same environment, handling the same type of tools, eating the same food etc. also assist the researchers at MC2 to form a common understanding of the world.

Two such understandings are the notions of the cleanroom as a symbol of "high tech" where cutting edge technology is created, and that working in the cleanroom is a visual and emotional manifestation of the value neutral scientist. A professor told me that his doctoral students, in accordance, like to put on the cleanroom suit and work in the laboratory as it makes them feel more like researchers.

The white cleanroom suit also makes researchers anonymous and takes away personal characteristics. Researchers who only know each other casually may accordingly not recognize one another, a notion expressed in the following manner by one of the members of the department:

> In the cleanroom you cannot easily distinguish the sex of a person, partly because of the suit, partly because everyone is busy working. It is hard to recognize who you see in a suit as you only have the eyes to go on. If it is someone you know only casually, you do not recognize him or her.

The cleanroom, thus, becomes a world of its own inside MC2 and researchers told me how they perceived it as an open society in which people helped each other out. "One can always talk to people in the cleanroom and ask about everything" one of the researchers explained. This open attitude in the cleanroom was, however, not liked by all and a small number of researchers told me that they preferred to work at night when there were only a few scientists in the cleanroom so that they could work by themselves, with no need to be bothered by others.

The process laboratory

Researchers at MC2 call the entire laboratory to which the cleanroom belongs "the process laboratory." Not all experiments are done there, though, since many of the research groups have their own laboratories where research is also done. These additional laboratories are office rooms that contain tools and machines, like burners or lasers. It seems, though, that most experiments on the nanolevel require at some stage the cleanroom, making it a central part of the research performed at MC2.

The maintenance of a process laboratory demands resources. The running of MC2 involves a maintenance and administration staff of 20 people with a budget of €5,5 million in 2003. The staff consists of administrators, cleaners, who have to clean a laboratory in which there is no visible dirt, and of maintenance engineers who are responsible for all the equipment and for teaching researchers how to work the machines. Apart from the maintenance and administration staff the process laboratory is where researchers work on their different projects. Even if the cleanroom has a capacity of 35 researchers, at no time during my visits were there more than ten scientists working at the same time.

To support the process laboratory at MC2 five floors with ventilation and support areas are required. The cleanroom laboratory itself is not attached to the rest of the MC2 building as it is directly secured in the

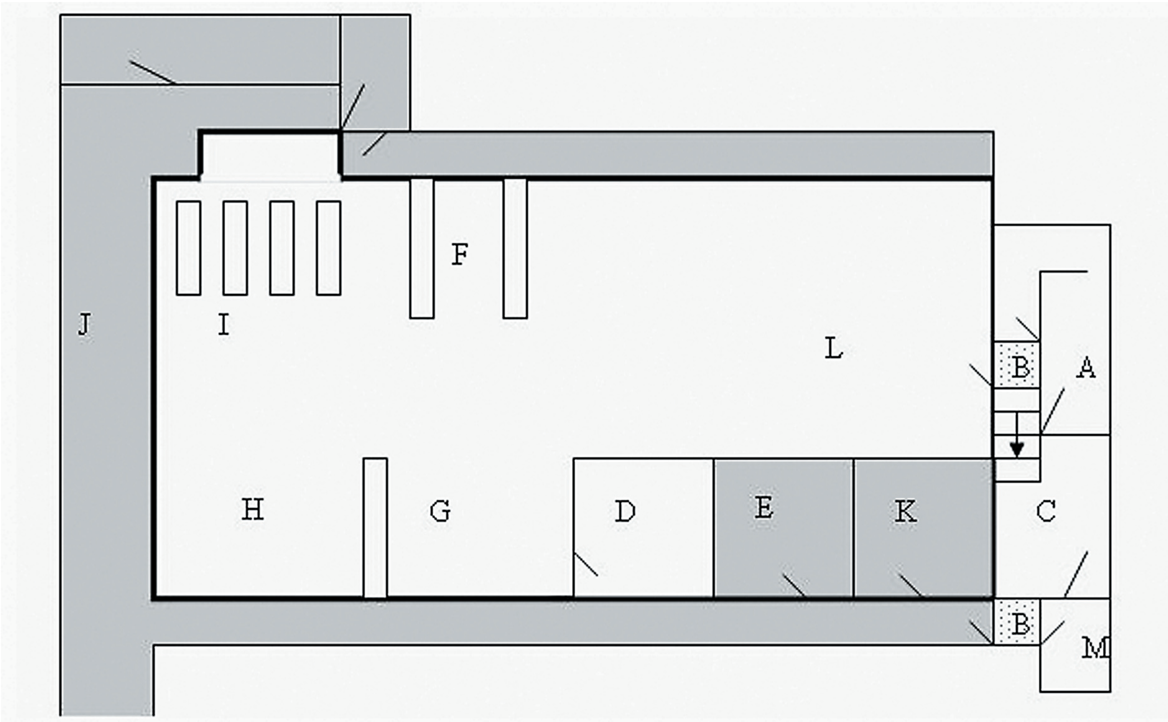


Figure 4. The process laboratory at MC2.

Gray area = Training laboratory
White area inside the thick line= Cleanroom
A + M. Dressing rooms
B. Air locks
C. Staircase connecting the process laboratory to the entrance above
D. Lithograph
E. Lithograph control room
F. Wet processing area (for use of chemicals)
G. Area of filtered light, used for lithography
H. Empty area, for future use
I. Silicon wafer manufacturing area
J. Shelves holding equipment
K. Microscope room
L. Assorted benches and machines

mountain below to reduce vibrations from outside sources. Immediately under the process laboratory is the maintenance area which contains a number of different machines, such as vacuum and cryogenic pumps used to remove and freeze particles. The reason for placing machines in the maintenance area is to reduce pollution and vibrations in the cleanroom but also to make maintenance easier as the machines here are accessible without cleanroom suits, which saves time for the maintenance engineers. All the gases used in the cleanroom come through pipes from the maintenance area and in reverse waste materials from the cleanroom are collected in large tanks. The maintenance area also has its own power supply if the electricity provided by the town should go down, making the process laboratory self-supporting of energy in the case of a power failure.

The process laboratory at MC2 is divided into two parts. Process laboratory 1, which is called *the cleanroom* and Process laboratory 2 which is called *the training laboratory* (see figure 4). The two areas have different levels of cleanness and sets of regulations. The training laboratory consists of corridors that circumvent the cleanroom with windows through which one can look inside and some windows through which one can look outside. The training laboratory contains a couple of rooms that are used for the messier processes such as cutting chips off silicon wafers that are so filthy that they cannot be done within the cleanroom with its strict requirements on cleanliness. To prevent pollution there are airlocks that separate the cleanroom and the training laboratory. Through these airlocks samples are transported between the two without any need to take them outside the process laboratory as a whole.

One of the maintenance engineers told me that a cleanroom is really about three things: keeping the right temperature, keeping the right humidity and keeping the right level of particles. “This is not as easy as it sounds” he added, hinting at the technical and logistical difficulties to fulfill the environmental requirements. To keep the temperature fixed at 21ºC with a humidity of 43% in the 1,028 square meters cleanroom and the 240 square meters training laboratory is somewhat of a technical endeavor, though it is probably an even more taxing task to keep up the standard of cleanness. To keep undesired particles out of the

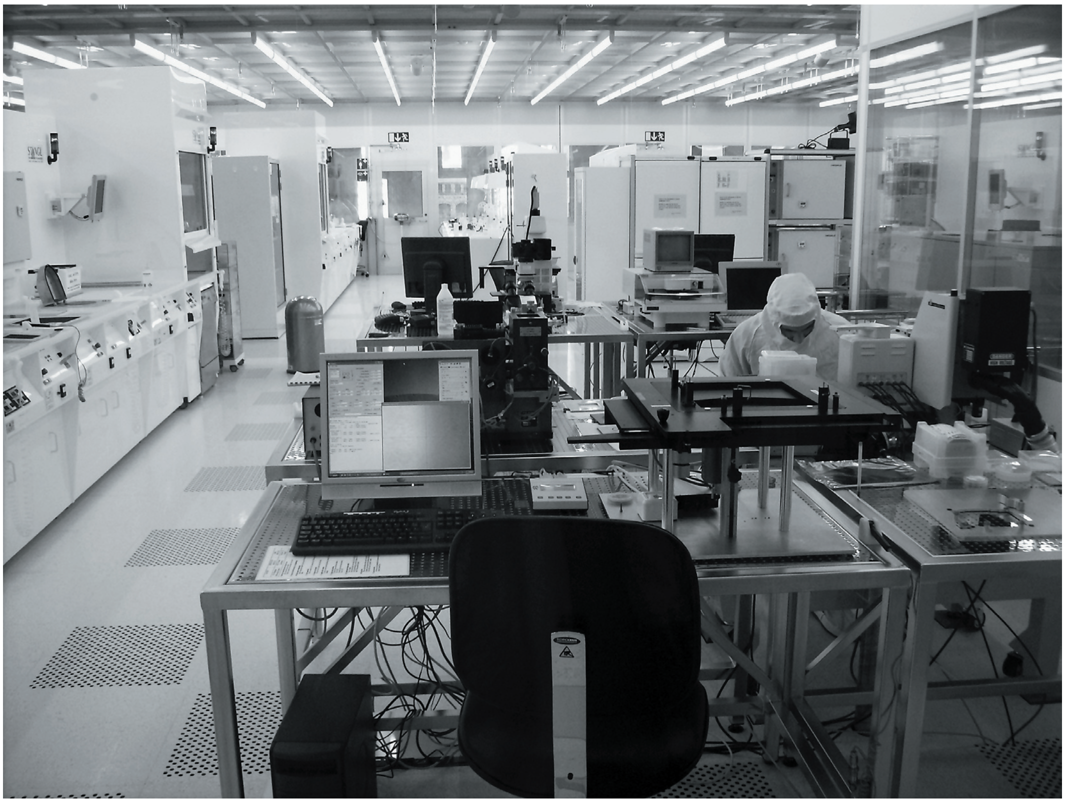


Figure 5. Area G used for lithography in which light is filtered.

process laboratory the air is first dried then it is re-moisturized before it is introduced into the air ventilation. Moreover, particle filters are placed in the ceiling and on the floor of the facility. These filters are placed directly above and below each other as the ideal airflow for removing particles in the air is through a straight vertical line. The particle filters remove all kinds of particles over 300 nm in size, including bacteria that are about 1.000 nm in size, which means that the only kinds of living beings in the cleanroom are humans.

These efforts to remove particles result in a cleanness level in the cleanroom of 1-1000 particles over 300 nm in size per cubic foot of air while the training laboratory reaches a cleanness level of 10.000-100.000 particles over 300 nm in size per cubic foot of air. In comparison, a normal office area contains over 100.000 particles over 300 nm per cubic foot of air. To guarantee good results when working with the lithograph, which can etch patterns 10 nm in size (located in area D, figure 4), requires a cleanness level of 1 which is an extreme degree of cleanliness.

This means that there is only one particle over 300 nm in size per cubic foot of air in the room. To reach this degree of cleanliness the lithograph is sealed off from the rest of the cleanroom and people only enter the lithograph room to place and remove samples.

A stroll through the process laboratory

To be able to move freely in the process laboratory one must take a half day long cleanroom clearance course. Without this clearance the facility can only be entered in the company of people with clearance and admittance is restricted to the training laboratory. With or without the clearance, when passing the locked door to the process laboratory, the first thing to do is either to cover the shoes, used for guests, or to change into special cleanroom shoes, if the visitor intends to work in the laboratory for a longer period of time, and then to put on a hairnet. Before going down a floor into the proper process laboratory area there is a primary dressing room with lockers in which the researchers can change into long-legged gym-shorts and a T-shirt as it gets hot inside the cleanroom suit. This dressing room is not well used since most researchers find it more comfortable to change in their own offices. Once dressed in shorts and a T-shirt one goes down into one of the two secondary dressing rooms. Since the training laboratory and the cleanroom have different dress requirements, different dressing rooms are also required. If going into the training laboratory one uses the "training laboratory dressing room" (marked M, figure 4) and if going into the cleanroom one uses the "cleanroom dressing room" (marked A, figure 4). For measurements and more polluting experiments the training laboratory is preferred, with its less rigorous dressing requirements. Going into the training laboratory one only needs to put on a laboratory coat and surgical gloves while admittance to the cleanroom requires a cleanroom suit. Because of the complicated dress requirements most researchers only enter the cleanroom when they need to and then only for the amount of time necessary to conduct the particular task they need to accomplish; it is thus not an area for hanging around in. In contrast, the training laboratory is an area where people can socialize more freely and it can be occupied by undergraduate students, guests looking around etc.

Figure 6. The cleanroom dressing room.

After using the training laboratory dressing room (marked M, figure 4) and passing through the air lock into the training laboratory, one meets with a long narrow corridor with windows looking into the cleanroom. Guests, such as politicians, reporters etc. are admitted into this corridor when they are given a tour of the MC2 facility. The narrow corridor opens up into a larger corridor where the wall is covered with shelves that hold all kinds of equipment used for experiments (marked J, figure 4). The training laboratory continues into a couple of rooms (not marked in figure 4) used for messier procedures such as cutting silicon wafers, and also to train undergraduate students. Old machines that have been replaced but are still working usually find their way into the training laboratory. A maintenance engineer showed me a machine in this section which he constructed during his student years, meaning that it must have been at least 20 years old.

When going into the dressing room that leads into the cleanroom (marked A, figure 4) the first thing to do is to wash ones hands and fore-arms to get rid of particles. Then one puts a hood over the hairnet which is fastened behind the head. The reason for starting at the top is to reduce pollution as particles travel downwards. To put on the suit is quite a balancing act since the outside of the suit is not to touch the ground nor the body, and the situation is not made easier by the elastic covering at the openings for arms and legs. During the cleanroom course one learns the importance of putting the suit on correctly; if it is put on too tightly friction is created, releasing particles, and if it is put on too loosely it creates a balloon effect which also releases particles. Once the suit is on, it is time to put on and tighten the boot-like foot protection and finally one puts on the surgical gloves. When fully dressed only the eyes and nose are uncovered. The reason for not using a suit that is completely covering the body is cost, since this also requires an internal air supply. After dressing up it is time to enter the airlock into the cleanroom.

Directly after passing through the air lock before going into the cleanroom, the floor at the entrance is covered with a sticky material to take away particles from under the soles of the shoes. Inside the cleanroom one easily breathes the purified air. The light takes away most shadows, and the temperature is set at 21ºC, being neither too cool nor too warm. In the background there is a soothing buzz from the air supply system and the noise level in the cleanroom is measured to 53 decibels, equivalent to a murmur. It is a room of moderation. People whisper to each other, if they talk at all. All persons in the room are identically dressed; it is only the size that differs. On the right and left hand sides of the room there are machines, tables, chairs and computer screens that are used for experiments (marked L, figure 4). There are also cupboards with locks containing plastic tool boxes clearly marked with the names of the researchers who have put their samples in them if they had to leave the laboratory before finishing their experiments.

On the left hand side there are three rooms, marked D, E and K in figure 4. The lithograph control room (E) cannot be reached from the cleanroom, but must be entered through the training laboratory. The advantage of this arrangement is that the lithograph can be handled without the cumbersome cleanroom suit. In the microscope room (K) researchers take nanometer scale pictures, which also is a process prefer-

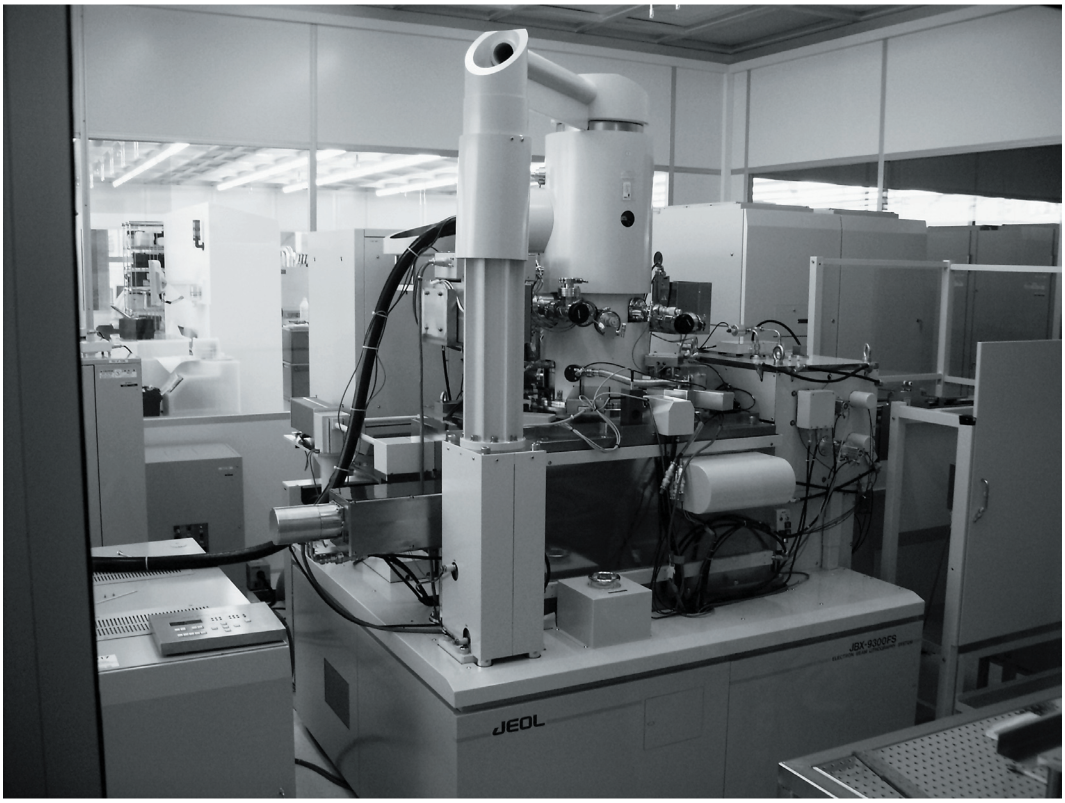


Figure 7. The lithograph, area D.

ably not done in the awkward cleanroom suit. To take a nanoscale picture one starts off in a larger scale and “travels” inwards on the chip and downwards in scale trying to find the correct area, a process that may take hours. The room which contains the actual lithograph (D) is sealed off from the rest of the cleanroom to reach a maximum level of cleanness, and it is only entered to place and remove samples. To the side of the lithograph, inside the cleanroom, is an area with a special glow since the light in the ceiling is filtered (marked G, figure 4). When manufacturing computer chips a process similar to developing photographs is used and normal light can ruin the process. This area was to me the strangest place to be in, as the intense yellow glow dominated over all the other colors. On the opposite side of the filtered light area is the wet process area (marked F, figure 4) consisting of two rows of benches. It is in this area that the polluting activity of handling chemicals takes place. When making computer chips it is mainly areas F and G that are used and, for the sake of convenience, the two areas are therefore placed beside each other. The far end of the cleanroom is used to cut silicon wafers, the basic material used to make computer chips (marked I, figure 4). Above area I on the map there is a small alcove which was originally intended to be the place for a particular machine that due to lack of funding was not purchased, and nowadays a wet bench used for work with certain polluting chemicals is placed there instead. Area H (figure 4) was initially also intended for a specific usage but, similarly, due to lack of funding it remains empty for future use.

The cleanroom experience is not something that only affects researchers when doing the actual experimenting. I was told that spending much time in the cleanroom may result in lowered immune defense as bacteria are filtered away. Others complain that they get a pale complexion by spending too much time in a room with no sunlight, and also by working at night. A more immediate effect of being in the cleanroom was described by a researcher who jokingly told me that the hairnet left a mark on the forehead and "that it is easily visible who has been down in the cleanroom as their hairstyle gets flattened by the hairnet and hood."

Polluting humans and control of nature

The construction of the cleanroom technoscape and the particular kind of behavior within it is influenced by the scientists' conception of nature. Research on the nanometer level has to be done in a clean environment in which humans need to cover themselves to protect the surroundings. Nanoresearch is, thus, conditioned by an intricate combination of conditions of nature and humans' will to manipulate matter. As mentioned earlier, dealing with the nanoworld makes observations based on immediate sensory experience hard and humans therefore need technology to make observations of nature. Hence, when it comes to nanoscience, the body is polluting and the mind is in need of control. In his study on cleanroom pollution Cyrus Mody (2001: 22) associates the laboratory with a *Foucaultian arena* for surveillance and discipline in accordance with Michel Foucault's (1977) suggestion that discipline sometimes demands closed environments that are not connected to other places in order to generate submissive and trained bodies.

In the manual used by the maintenance engineers who handle the cleanroom courses at MC2 it is specifically stated who can and who cannot be allowed into a cleanroom and how they who have entered must behave.

> * Persons who are in a cleanroom shall behave calmly. Tense, nervous persons and those who easily lose their temper should not work in cleanrooms. Nervousness causes unnecessary movements, leading to extreme particle detachment. Strong emotions caused by bad temper can cause exaggerated sweating, unnecessary movements and reckless behavior.
>
> * It is obvious that people suffering from phobias should not work in cleanrooms. Persons with emotional problems and those who cannot subordinate themselves or follow orders shall also be exempt from working in cleanrooms. Nowhere are rules and regulations as important as in cleanrooms.
> (Månsson 1992: 64-65 [My translation from Swedish])

The personal hygiene of those who are to enter the cleanroom must be up to a set standard. Those who have a cold or a skin disease should not work in the cleanroom due to the extra contamination. While obtaining the cleanroom clearance, there was an overhead showing that even with protection and proper training humans are the most contaminating objects in a cleanroom, responsible for 35% of the contamination, while process equipment emits 25%, chemicals 20%, and processing 20%. Without proper protection humans drop about 10.000 skin fragments the size of 3.000-5.000 nm per minute, a process that is drastically reduced by wearing cleanroom clothes which keep the skin fragments on the inside. The table below shows a comparison between the numbers of particles equal to or greater than 500 nm in size, emitted per minute by the human body clothed in different kinds of dress.

Action	**Ordinary clothes**	**Cleanroom clothes**
Sitting, slight hand movements	500 000	15 000
Standing up	1 500 000	80 000
Walking slowly	5 000 000	150 000
Running	10 000 000	300 000

To reduce the number of released particles and to ensure they drop to the floor without contaminating samples, human behavior needs to be controlled. It is important, for example, not to lean over the experiment as this breaks the straight airflow from ceiling to floor and skin pieces from the researcher may whirl about and destroy the sample. It is also important to move upright and slowly, again not to break the straight vertical air flow. Figure 8 illustrate how working benches and humans need to be placed in positions so that the line of air flow does not create a swirl.

Also the acoustics in the cleanroom are controlled. In fact, most sounds can interfere negatively with experiments, either directly or by distracting the researchers (cf. Mody 2005: 180-181). For instance, the whiz from the ventilation fans makes some of the researchers drowsy, thus interfering negatively with their experiments. The negative interference of acoustics is also a reason why people whisper to each other if they talk at all in the cleanroom. When giving me a tour around the maintenance area one of the engineers said that in the beginning music was played in the cleanroom. However, since the researchers come from all over the world and have different musical tastes it was hard to find music that was acceptable to everyone. As a consequence they stopped playing music and thereby underscored the idea of the cleanroom as a neutral environment suitable for all researchers. By keeping the cleanroom clean from most sound it becomes one of few environments in today's society that is quiet, apart from the whiz of the ventilation fans, making it something unusual and probably enhancing the experience of the cleanroom as an extraordinary place.

As always seems to be the case when it comes to systems with strict regulations there are rule-breakers and it is not uncommon that the cleanroom rules are intentionally broken for the convenience of the researchers. Smokers, for example, should wait 10 minutes after having smoked and rinse their mouths before entering the cleanroom; a rule that is not always obeyed. Some smokers who know they will be inside the cleanroom for many hours may use moist snuff instead even though it is also forbidden. However, since the mouth is covered by the cleanroom suit there is no way of telling if a person is using moist snuff

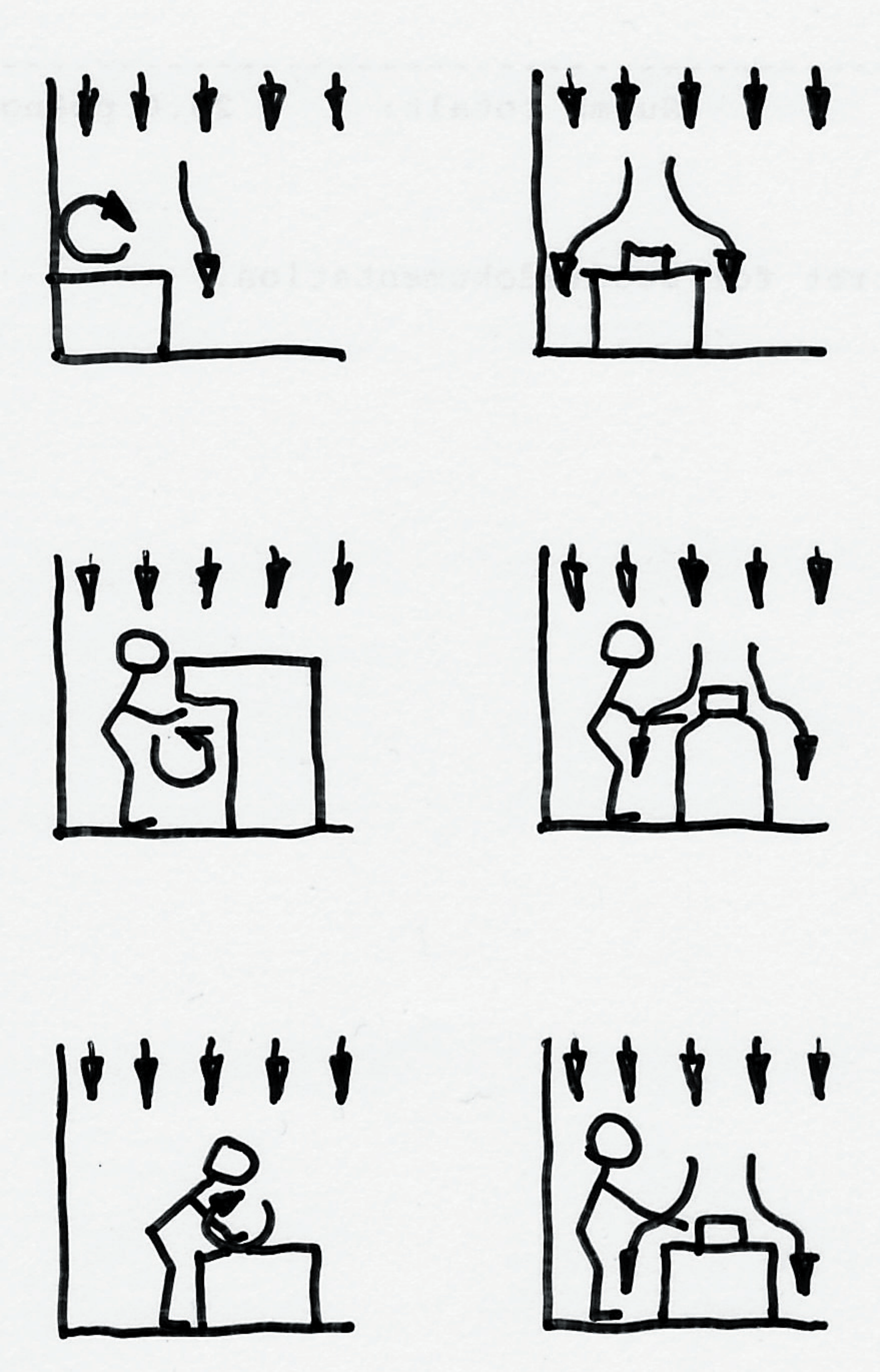


Figure 8. Drawings made from overheads used in the cleanroom clearance course. Correct behaviors to the right and incorrect to the left.

or not and detection and subsequently sanctions are unlikely to follow. Another kind of rule-breaking that can be encountered in the cleanroom is the use of cell phones, which are not allowed but may be brought along if there is an urgent call expected. These incidents mostly occur when experiments are not affected by the rule-breaking. The rule-breaking is, of course, rarely done in front of others working in the cleanroom since rule-breakers may be reported and ultimately banned from working there by the maintenance engineers. There have been incidents when people have been warned, according to the maintenance engineers, but there are no incidents of people being banned from working in the cleanroom at MC2. Other types of rule-breaking in the cleanroom may be unintentional and connected to the articulation of feelings. A researcher described how she sometimes started to wave her arms about when excited, something she thought she needed to control, while another researcher described how he once got pushed away by a colleague. Both stories show that scientists who work in the cleanroom cannot always control their emotions and that research sometimes is an emotional endeavor. Waving the arms and pushing people are, however, expressive behaviors, visible for others, and therefore more easily leading to a reprimand. What both intentional and unintentional rule-breaking have in common is that individual urges need to be controlled in the cleanroom, no matter if it is an urge to smoke, receive important phone calls or to wave ones arms about when happy. In this sense the cleanroom is a closed area for surveillance and control in accordance with Foucault (1977). It is a type of control, however, that seems mostly to deal with self control in which each researcher tries their best to comply with the rules and suppress their personal urges.

The importance of complying with the rules was emphasized when taking the course to get my cleanroom clearance. The course ended with a film on cleanroom behavior. The final sequence described a researcher who failed an experiment due to carelessness in the cleanroom and the speakers voice declared "A failed result may not be so important for the researcher but think of other people," while, at the same time, a picture of a baby in an incubator was shown. Thus, the explicit rationalization for the discipline and surveillance in the closed space of cleanrooms as presented here was not for facilitating research but for the general common good. The researchers themselves, on the other hand, seemingly follow cleanroom regulations to accomplish their personal experiments without too much concern for the general public.

The cleanroom facility itself is a closed self supporting system which means that it can manage without external support of electricity or air for some period of time. Everything that is allowed into the cleanroom is purified and controlled, including air, vibrations, light, gas and water. Experimental materials should be in ideal form, i.e. in a purer form than found in nature, as it is by keeping materials pure that researchers can study the properties of them. If contaminated the researchers cannot be sure which elements in the sample contributed to the readout. The cleanroom is thus an improved environment in which researchers rarely work with material in their natural state. There is accordingly a transformation of nature from a "raw" natural state, not manipulated by humans, to a "pure" state in which nature through human manipulation has been improved; a transformation which is an attribute of domestication in which humans take material from its natural environment, subjugate it and use it in production processes (Ingold 2000: 73, Knorr-Cetina 1999: 28).

Researchers when experimenting try to control as many factors as possible. It was for example explained to me that silicon is preferably handled in cleanrooms as it easily interacts with other elements. As all external factors must be controlled in the cleanroom it is important not to bring in things from the outside. Ordinary paper, for example, is not allowed because it contains fibers that pollute and therefore special cleanroom paper is needed. Of greater concern for the researchers is the condition that the purified air makes people thirsty and containers of water are not allowed into the cleanroom due to pollution.

By reducing external influences the laboratory is made into a local intramural space in which universally valid and objective science can be conducted. It does not matter in which cleanroom a specific experiment is done as it should be repeatable in all cleanrooms with the same standards. Following the global nature of nanoscience with researchers moving between different facilities exchanging results there is a need for a unified standard between different cleanrooms. Through this standardization process a universal cleanroom technoscape is produced in which the researchers feel “at home,” no matter in which facility they do their research. In a concrete way this underscores their feeling of belonging to a global nanoscientific community and that they are all engaged in a common exploration of nature’s true characteristics.

An important part of reducing contamination in the cleanroom is that the researchers learn the proper skills to avoid unnecessary pollution, skills that through time become almost instinctive. Once in the cleanroom a researcher told me not to lean too much over a sample as I might contaminate it. He also told me that as a novice he had done the same thing, letting curiosity take over, and in the process he had ruined a sample. Nowadays, it was instinct for him to sit up straight when working in the cleanroom. Even such a mundane task as sitting straight emphasizes the connection between modes of behavior and being in a technoscape, as each landscape requires its own code of acting.

A person skilled in proper cleanroom behavior using those behaviors outside the cleanroom would look rather strange, whispering and moving slowly forwards with arms hanging straight down. A video used in the cleanroom clearance course shows how non-cleanroom behavior creates pollution and all the spectators laughed when a person in the video smoked and ate while in a cleanroom. Thus, cleanroom behavior is not only about learning new skills it is also about unlearning, i.e. learning how to get rid of polluting behaviors. The process of learning and unlearning how to act is to a high degree determined by the particular requirements of research on the nanometer level, research associated with the necessity of a clean environment. Thus, when a researcher told me that she needed to control her arms when excited in the cleanroom, the need to unlearn this behavior is conditioned by the state of nature that is maintained in the cleanroom.

Nanoscience and technology

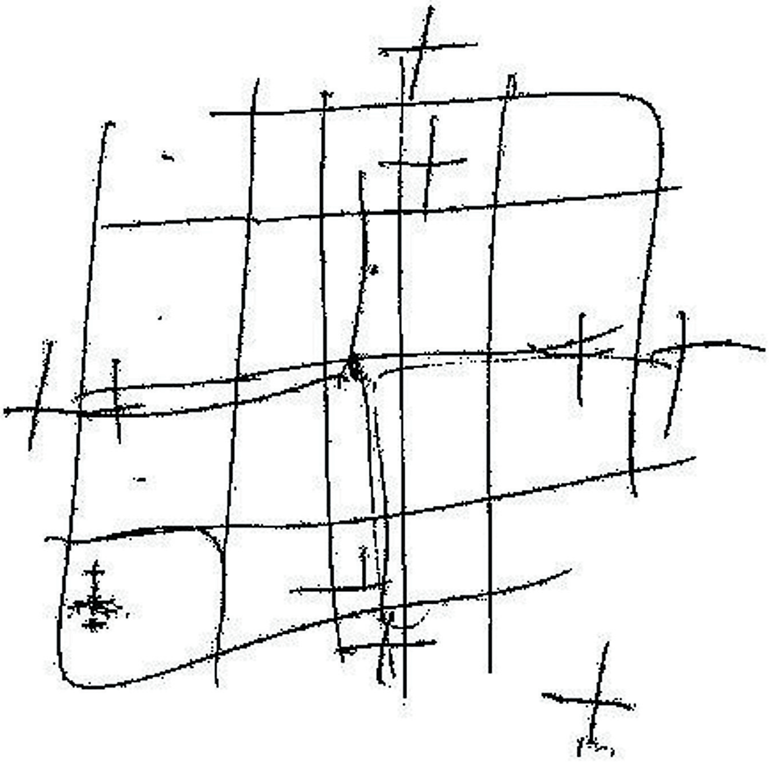
Due to the miniscule scale, humans need devices for seeing and manipulating objects in the nanoworld. As manipulation of matter becomes increasingly smaller, the devices used become increasingly complex and many of the machines in the cleanroom have been manufactured in other cleanrooms which demonstrates the need for high technology for the development of new high technology. Moreover, and perhaps paradoxically, the size of the machines grows as the level upon which humans make their manipulations goes down in size.

Talking to nanoscientists about technology is not easy as it is something which they ordinarily do not reflect upon. Technology is such an integrated part of the nanoscientific technoscape that the scientists take it for granted as a part of everyday life. A researcher even admitted when he came to know me better, that he had felt intimidated by my questions about technology when I first appeared at MC2. He felt that I had almost forced answers from him regarding a subject that he had never really thought about. Later, when we were better acquainted, he described how in everyday work, machines and skill get entangled, not making it easy to separate the person handling the machine from the actual machine itself. To look, for instance, into a microscope is an acquired skill which over time becomes instinctive. The only purpose of the microscope is to enable the observation of a dimension of the world that cannot be perceived by eyesight. The microscope, thus, becomes an extension of the researcher to get improved vision, in the same way that glasses becomes an essential part of the near-sighted. In a famous metaphor Gregory Bateson (1973: 434) questions the tendency to conceptualize the self as something that exists only inside the organism. For a blind person, Bateson argues, the walking stick becomes an extension of the sensory organs and of the blind person's conception of the self as it gives information on how to move around in the world. In a similar manner technology becomes an integrated part of the nanoscientist. It is not at all clear where the borders of the scientist start and stop as a nanoscientist without technology would not be able to do much research on the nanometer level of existence.

The machines used by nanoscientists become the means of mediation between the nanometer level and the level of existence perceived by humans, as was explained to me "We rely on modern technology to see the carbon nanotubes, when we work on them we do not know if they are there." This notion of working with things that cannot be experienced directly means that the researchers often use objects found in the surrounding technocape as metaphors to visualize this non-visible dimension of the world. A researcher, for example, explained that it was frustrating to work on carbon nanotubes as they could not be seen through machines and that he pictured them as pen shaped, as a way to ease his experimentation on them.

The role of technology as a mediator between humans and nature can be described in different ways. Latour and Woolgar (1986: 51) emphasize the interpretation of nature into numbers by machines and use the term *inscription devices* to describe how scientific machines transform material substances into diagrams that subsequently can be used in scientific documents. Peter Galison (1997) argues that the machines used in microphysics belong to two different traditions. Firstly, there are devices that produce pictures and link our senses to the microworld, known as *image-making devices*, and secondly, there are *logic devices* that produce numerical readouts on screens and papers. Latour and Woolgar's inscription devices seem mostly to be logical devices while among the researchers at MC2 there is a preference for the image-making devices. Experimentation at MC2 mostly consists of manufacturing and measuring which in this miniscule scale creates a need for visualization. Even among theorists there is a preference for image-making and several of them use visual computer models to illustrate calculations as a way to understand what happens on the nanolevel.

Visualization is, for instance, used in the process of the manufacture of computer chips. A silicon chip is sometimes seen as a landscape, where you need to orientate yourself. In fact, finding the way on a chip is even called "traveling," and a good way to "travel" on a chip is to start in one corner and move inwards using deformities as landmarks. Some of the researchers at MC2 even draw maps on paper, marking out deformities, to find the way on a chip. Figure 9 shows one such map in which the target area is in the lower left corner, marked by small crosses. The larger crosses on the map are markers on the chip used to aid the etching process. In contrast the grid pattern is only imagined and corresponds to cartographic latitudes and longitudes and it is consequently used for orientation, as a way to get a grip on space intervals. This drawing can be compared to a photograph of a similar chip taken in micrometer scale.



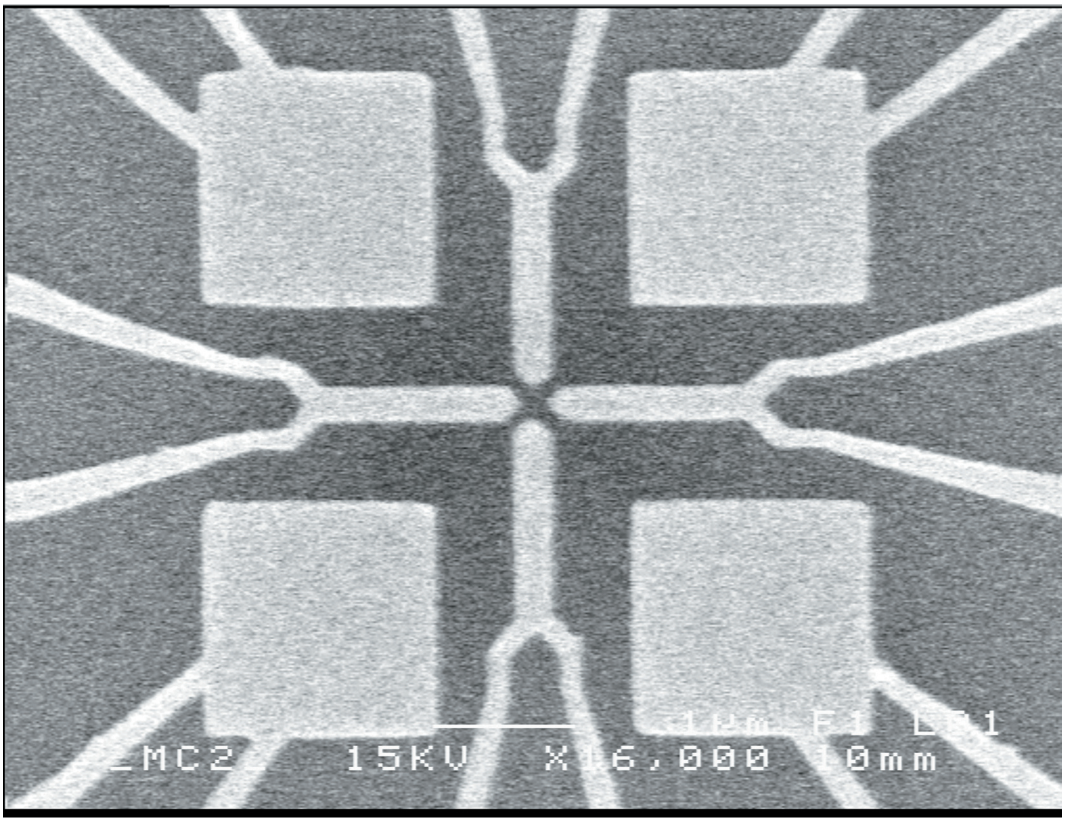


Figure 9. Photo by Omer Nur, Chalmers University of Technology.

Since human sensory experiences are subjective and the researchers want observations that are objective the scientists need to surpass the body to make stable and coherent observations of nature. Machines, in this instance, do not only give nanoscientists visualizations of the nanometer scale, they also produce quantifiable results and therefore they are felt by the researcher to ascertain the production of true observations of nature. A researcher who spent much time in the cleanroom underscored that even though measuring errors can occur the results that come from machines are otherwise in accordance with reality. "Measurements are more reliable than theory and I trust experiments first" he continued, adding that to detect errors is an important part of his research and serves to make these errors as small as possible.

As it is inanimate machines and not humans that make the actual observations of the nanoworld, the results are conceived of as objective, as if nature introspectively gazed into itself through the machines. This de-humanization of experimentation is also found in everyday discourse. Before entering the cleanroom, for example, personal objects such as cosmetics, rings and wristwatches should be taken off, and once inside the cleanroom suit, people look similar. In accordance with this depersonalized attitude researchers sometimes also talk about their work in the grammatical third person and instead of saying "I use silicon wafers" they say "one uses silicon wafers," with the effect that they distance themselves as individuals from research (cf. Ochs et al 1994, 1996).

Skills

The individual skill needed for handling various machines is important and, in accordance, when asking doctoral students what they thought was the most important thing/skill they learnt during their education several answered that it was to operate machines. However, the machines in the cleanroom are not for all to use since a license is needed for operating each one and these are issued only by specially assigned maintenance engineers. They make sure that each license holder has the acquired level of skill to handle the particular kind of machinery properly. These licenses are commonly called driver's licenses and they give the researcher permission to handle a specific machine. Consequently, the maintenance engineers become gatekeepers with the aim of limiting the likelihood of machines breaking down due to poor handling. A number of the maintenance engineers complained about uneducated researchers who did not have the proper skills to handle the machines correctly and therefore the machines had broken down. To repair a maltreated machine might cost thousands of Euros signifying a considerable economic stress on the budget of the laboratory. The repair of these machines is, however, not only an economic question as it may take up to a couple of weeks to have them functioning properly; spare parts or service specialists may have to be sent for, creating bottle-necks in the research process.

Without a license the research has to be supervised by a maintenance engineer or be conducted by someone who does have the right authority. In reality it is common that the actual learning process to handle a machine is done by licensed researchers while the maintenance engineers just supervise the actual examination. According to the researchers, some driver's licenses can be hard to acquire, since making appointments with the maintenance engineers handing them out may be difficult. To get a license becomes a negotiation between the individual researcher and the maintenance engineer responsible for the machine but if a researcher is refused or finds it difficult to get a license, the group's professor may get involved, negotiating a solution with the maintenance crew. As the machines have different levels of complexity, they take more or less time to master. To learn how to handle the electron microscope, for example, may take a month while the use of other machines may only take a few hours. Those who have licenses and skills to handle machines that take a long time to master are of course in demand, both as teachers and as researchers since they may assist in other peoples' experiments.

For experimentalists, who are in constant need of different apparatus, there is a seemingly never ending process of negotiation to get access to machines. It is important to book the machines needed in the cleanroom in advance and a few machines, such as the lithograph, are in great demand. Since there is a fear that the machines may break down it is important to do as much experimentation as possible with the ones that work. Thus, there is a negotiation between individuals, in a process of mutual exchange, in which access to the machines and assistance in handling them can be given away or received.

Since research groups have to pay a fee for every member who is allowed in the cleanroom the training of a new person signifies a double cost. First they have to pay for the person who needs the training and then they have to pay for the teacher, who on top of that, is prevented from or slowed down in doing his or her own research. As a strategy to lower costs, it is common that those who are allowed to work in the cleanroom do research for those who may not enter. This strategy does not only save money but also time. Experiments are done faster and are less likely to fail if undertaken by an experienced researcher than by a novice.

Experimentation seems to involve two different types of skill; *personalized skills* that require experience and a feeling for the process, and *depersonalized skills* that can be automated by machines. Personalized skills are held by a subject and are accordingly more adjustable to the actual surroundings and in constant change as the subject becomes more and more enskilled. Enskillment is an individual process of trial and error and learning from others, from which an intuitive feeling for the process is developed. This is in contrast to depersonalized skills that are quantifiable and rigidly formalized. The machines used in the MC2 cleanroom are, for example, of a more general kind, constructed to deal with more variables than similar machines used in industry, as experimentation work relies on personalized skill to a high extent.

The divide between skills possessed by subjects, dealing with gut feelings, and more formalized types of skill has been explored by Ingold (2000: 316-317) who separated between skills used by a craftsmen, *technē*, and activities performed by manual operated devices, *mēkhanē*. According to Ingold the use of machines has been a historical process in which humans go from the centre to the periphery of the labor process and manufacturing goes from being personal to impersonal.

Among nanoscientists at MC2, however, the important divide between skills is seemingly to separate between skills relying on gut-feeling and skills that can be quantified, and the transference from the former to the latter. For example, to experimentally manufacture computer chips at MC2 requires personal skills. To know for how long to expose a blueprint on a chip to light is something that takes gut-feeling. It is a question of balancing insufficient exposure, which means that the full pattern will not appear, against overexposure which will ruin the whole chip. How long to soak the blueprint in a remover is also something learnt by doing; leaving it too long means that the blue-print may start to dissolve, while taking it out too soon means that the blue-print will not be fully developed. Failing to time the various processes correctly means that the researcher has to start the whole process over again and as a consequence, enskillment of producing computer chips becomes a process of trial and error over a long period of time during which an intuitive feeling is developed.

One of the experimentalists in great demand described personalized skills in the following manner.

> You cannot learn in a book how a particular machine works. You have to feel it… Everything is a problem at the nanometer level. The machines have to be set exactly correct. As you cannot see what you are experimenting on you need to get a feeling for it. You get a feeling when the experiment is ready. Experience is the most important thing in research.

Personalized skills are consequently largely based on individual experience acquired by acting in the particular environment and thereby developing a feeling for, for example, the proper exposure time of a blueprint. Depersonalized skills, on the other hand, may be reduced to automated logical steps, such as mass-production of computer chips, making the skill available not only to other researchers but also recreateable by machines. Ideally, natural science is about developing depersonalized skills as these skills can be adopted by scientists all over the world without the need for personal instruction. The use of formulas, for instance, assists researchers in creating routines that facilitate research and a theorist told me that the purpose of mathematical formulas in nanoscience was to create routines for specific stages in experiments so that researchers can use their time to experiment on stages that are not yet logically understood.

For experimentalists the difference between personalized skills and depersonalized skills becomes important when it is time to account for the research. There is then a need to quantify gut feelings, i.e. to go from the personal non-formalized skills acquired by the scientist in his or her practice to formalized repeatable skills detached from the individual researcher. The whole process of going from single experiments to mass production of a finished product signifies a transformation of personalized to depersonalized skills. It was also maintained by nanoscientists at MC2 that it is the conversion from single chip to automated mass production that is today's biggest challenge for nanoscience thus making the translation of personalized skills into depersonalized skills crucial for the future progress of the discipline.

The involvement of machines and depersonalized skills in scientific practice also serves to reduce human subjectivity as the machines offer researchers a freedom *from* personal engagement, such as interpreting nature by one's own senses, thus creating objectivity by letting nature speak for itself (cf. Daston & Galison 1992: 82-83). In a sense, the process of going from personalized to depersonalized skills can be described as a process of mimicking machines (cf. Collins 1990). For nanoscientists' the transformation from personalized to depersonalized skills also means a transformation to machinelike attributes such as repeatability, regularity, predictability and lack of emotions. Thus, principles which are ascribed to machines are also seen as ideal for conducting good science.

Mimicking machines and idealizing lack of emotions in research may, for people who do not share the scientists' ideal, seem dull and almost unhuman but one has to remember that machines and humans are often ascribed different symbolic values wherever one advocates romanticist or rationalist ideals (cf. Norman 1993: 223-224). During the industrial revolution the machine became a divided symbol among the literary elite. For the defenders of aristocratic and romanticist ideals, machines became a symbol of destruction, something that stood in opposition to the soul and represented spiritual decay while, in contrast, liberals and philosophers of enlightenment saw machines representing progress and rationality (Helldén 1986: 122-123). For machine critics, humans are flexible and curious while machines are rigid and stupid while technocrats see humans as illogical and vague and machines as logical and precise. The researchers at MC2 mostly seem to promote the technocratic ideals and consequently they stress the positive values associated with machines. Thus, when nanoscientists describe how they need to control themselves and make their behavior more machinelike this is not seen as something negative since the use of machines and depersonalized skills are congenial with the idea of a value free science. From the researchers' perspective, machines make value free readouts that supposedly are not affected by any subjectivity. Dressed in the practically identical white suits and in the strictly controlled environment of the cleanroom, individualizing characteristics are erased. From this technoscape a collective of similar looking peers who make similar observations of nature emerges, which from the researchers perspective is both a precondition for properly doing research as well as a mark of the quality of the research that is undertaken.

Anthropomorphic language

That many physicists use anthropomorphic language when they talk about their research is well documented. Among high-energy physicists studied by Traweek (1988) and Knorr-Cetina (1999) detectors were anthropomorphized. Knorr-Cetina (1999) describes how detectors become, linguistically, social and moral beings that age and have a temper while Traweek (1988: 157ff) depicts how genital metaphors were used around detectors, seen in acronyms such as SPEAR and SLAC. These genital metaphors are, according to Traweek, connected to the idea of scientists as male and nature as female, where detectors become the site of copulation between scientists/male and nature/female. In a similar manner, nuclear weapon physicists have been reported to de-humanize people by using machine analogies for humans while machines are anthropomorphized (Gusterson 1996: 120-124). People are described as "human resources," communication becomes "interfacing" and miscommunication becomes "disconnects." Machines, on the other hand, are anthropomorphized and missiles have "skins" and "heads" while the best weapons are "smart bombs," implying machine intelligence. The reason to de-humanize people and to anthropomorphize machines is two fold, according to Gusterson (1996). De-humanization makes it easier for researchers to conduct science that may hurt people, while the anthropomorphization of machines makes it easier for the researchers to work with them.

In contrast to the examples above, the researchers at MC2 as a rule do not use anthropomorphic language for machines and, for instance, the lithograph is plainly referred to as "the lithograph." They may, however, use anthropomorphic language when describing matter; sometimes electrons are jokingly referred to as lazy and atoms are described as being attracted to each other. A researcher described atoms and nanotubes in the following metaphoric and anthropomorphic manner:

> … I try to know them [the atoms]… I see atoms as solid balls, atoms are something we use to make things better, it is evolution. Nanotubes consist of a lot of atoms. Nanotubes are like clothes, it is a material, but it is a very expensive material. It is like salt in food, it makes it tastier. Nanotubes form a sexy material that is sturdy and light. Nanotubes are like a very nice dress in the fashion world. Everyone wants to own that dress. It is a hot topic… I like to be in the area of hot topics. I want to work with new stuff. I'm curious of how they are [the nanotubes]. Every day there is something new. Today they are curly, tomorrow they are straight. If they become different next time they are grown, it is not because of them, it depends on temperature, pressure etc. I think we have to grow them as they like, we cannot control them today. We have to accept their behavior. We have to give them a little freedom. I do not think it will be possible to control them in a near future. It is nature and we have to accept it, nanotubes will not be controlled in the next 20 years at least. Nanotubes are something that has been discovered, they existed in soot as long as there has been soot, but it is a new material.

The use of metaphoric and anthropomorphic language does not mean that the researchers' classify nanotubes as alive or that they demonstrate consciousness in the form of feelings or agency. What we are dealing with are two types of *sociolects*, i.e. a variety in language based on social background or status. There is accordingly an everyday language use and a scientific language use. The scientific way to describe the growth of nanotubes would be as formulas for chemical processes but since this is a complicated form of verbal communication it is mostly limited to the writing of scientific texts. Everyday language use is found inadequate to describe a cosmology based on inanimate matter since from an academic perspective language should refer directly to fixed conventional definitions. The dynamics of everyday language means that such language is constantly changing, making it unfit to represent the allegedly universal truths (Bicchieri 1988: 102, Daston & Galison 1992: 81). The physicist Krister Renard (1995: 139) moreover argues that our linguistic concepts, all taken from the macroscopic world, are not well suited to conceptualize microcosmic conditions and, as a consequence, a new language has to be invented to describe microcosmic phenomena.

When researchers talk about growing nanotubes the expression "to grow" is, accordingly, to be understood as an analogy. A researcher explained that the expression has nothing to do with describing life and that it refers only to the structural likeness between the growth of trees and the construction of nanotubes. The term "grow" deals, thus, with an analogy from macrocosmos, where it is used in the sense of "increased size of an organism," to microcosmos, where it is used in the sense of "increased size of matter." The reason for using the term "grow" when describing the construction of nanotubes is to get people to grasp the development process in an easy way without using complicated chemical formulas. The expression "to grow" is therefore used to simplify communication between individuals who share the same set of meanings but at the same time may cause confusion and misinterpretation among people who do not share them. Thus, laypersons are sometimes confused as to the meaning of the terms used by scientists. To portray nanotubes as sexy, for example, is a metaphor that emphasizes the novelty of working with nanotubes, i.e. cutting-edge science, and describes an emotional connection between the researcher and the object of study and consequently is not to be taken literally.

Conversely, researchers at MC2 sometimes use scientific concepts to describe non-scientific activities as they, in accordance with other communities, use the environment where they function as a source for making appropriate analogies and metaphors. During a coffee break, for example, I was treated to some home made cheese cake and a discussion broke out regarding how to make it. After a while we all started to laugh as the descriptions sounded just like the process of lithography, "you add a layer of this and then add a layer of that…." This does not imply that the nanoscientists see a connection between cheese cake baking and lithography, just that it is possible to use a nanoscientific language to describe the process of making such cakes.

Summary

For the people at MC2 the cleanroom is the heart of the research facility as most of the scientists sooner or later need the confinement from pollution presented by the laboratory. The employment of cleanrooms is actually a necessity for the domestication of the nanoworld due to nanotechnology's sensitivity to pollution. For the researchers the cleanroom is a technoscape, a landscape constructed by humans based on technology in which humans interact with nature. Together the researchers form a common understanding of the basic conditions for this world through the daily interaction of being in and around the laboratory.

By eliminating as far as possible all types of external influences the cleanroom becomes an intramural universal space separated from the local outside world. This process includes the humans working there, who need to control themselves mentally and physically, and who, thus, contribute to the notion of the cleanroom as a visual and emotional manifestation of value neutral science. The cleanroom acquires an ambiguous status, being at the same time a local *and* a universal space; a local intramural space in which universal objective science is conducted.

As it is hard to observe the nanoworld through direct sensory experience, humans need technology to make such observations of nature. In the cleanroom, technology allegedly gives us correct observations of nature and can be seen as the mediator between subjective humans and true nature. The skills needed for handling the technology are consequently crucial for the researchers. To function in the cleanroom it is not only important to acquire new skills it is also important to unlearn certain habits that may ruin experiments. The skills learnt, however, are both an individualizing and a collective endeavor as it is through social networks, learning from colleagues and maintenance engineers that individual skills to handle the machines are acquired. The skills used by the scientists at MC2 can roughly be divided into two types; personalized skills that require gut feeling and depersonalized skills that can be transferred to machines. The aim of research is often to go from individual personalized skills to universal depersonalized ones which are accessible to scientists all over the world without the need for individual instructions. The aim of generalizing personalized skills is associated with the notion of an objective science in which the individual researcher is of little or no importance.

7. Epilogue: next to nothing

On a return visit to MC2 the poster declaring "We offer next to nothing" was gone. The slogan which I had seen almost daily during my fieldwork had been removed from the facility entrance as there obviously is a need for new catchphrases as time goes by. For me the slogan has become an inspiration for the understanding of how researchers at MC2 constitute their professional lives. The nanoscientists being the "we" in the slogan can themselves be described of as being "next to nothing" in two ways. Firstly, they study dimensions of the world that are constituted by the smallest stable building blocks of nature, i.e. nature's "next to nothing." This, I guess, is the intended meaning of the poster. Secondly, when the nanoscientists conduct their research they want to reduce themselves to a "raw subject," that is, to their purest form, thereby taking away collective and individualizing attributes such as culture, gender, emotions and so on. This alternative interpretation of the slogan gives us insights into a community which emphasizes individualism to the extent that it merges with universalism; as it is by making individualizing attributes irrelevant that science becomes universal.

When researchers at MC2 describe humans as lumps of carbon atoms or when they tell physics students that feelings are basically chemistry, they are describing humans and feelings from an objectivistic stance. This outlook of the world is in accordance a nanoscientist's definition of nature which may be defined as "… everything of purely material character that we can, or can conceivably, observe and measure" (Rosen 1995: 169). This objective stance does not mean, however, that they are unaware of human subjectivity in research, just that human subjectivity is something that ideally should be reduced to next to nothing. Serious research I was told "is to work objectively and not to interfere with the outcome."

The aim of this thesis has been to explore *cosmological notions of the nanoscientists at MC2 and how such notions are created, maintained and strengthened through their conceptualization of nature and self as founded in the everyday practice of being a scientist.* These cosmological notions are, like all cosmologies, entangled with everyday practices and part of people's lifeworlds and deep emotional investments. At the core of modern scientific cosmology is the notion of an inanimate nature ruled by laws that can be manipulated and controlled by humans and the obvious aim of nanoscience is accordingly to understand and control matter at the nanometer level. In an inanimate nature life is an epiphenomenon where humans are subjective beings with limited senses that are inadequate to properly examine nature itself. To minimize distortion, i.e. subjectivity, when studying nature there is a presumption of objectivity which places objects in the centre of research, following a chain of argument:

* Nature consists of inanimate matter (such as atoms).
* Humans are part of nature.
* Life and sociality are epiphenomena of nature.
* To understand nature humans need to get rid of epiphenomena.

The ideal would be to get rid of humans altogether but then there would be no science as research requires a subject who is curious as to how the world functions. The aim of being objective is, thus, not to get rid of human subjectivity but to reduce its influence on the matter of study to "next to nothing."

Colors, for instance, can be perceived from two different perspectives. From a subjective stance colors are distinguished and categorized by individuals who give them names such as blue and red. From the objectivistic stance, colors are photons with different wavelengths. The accurate way to describe colors from the objectivistic stance is therefore to refer to their wavelengths, which, from the scientists' perspective, is a universal measurement not dependent on cultural notions of color coding. Objective color coding is thus a collective standard used by all researchers. This means that the individual perception of color is of no importance when studying wavelengths of photons.

To obtain this objective stance it is necessary to construct a technoscape which separates the objective and universal from the subjective and local. Objective knowledge is thus supposedly disembedded from individual subjects and is therefore not tied to specific localities or historical moments. Subjective knowledge, in contrast, is directly connected to a subject and therefore tied to a specific locality and a particular period of time. To pursue objective science it is crucial to establish scientifically intramural technoscapes that are separated and independent from the subjective local societies by which they are surrounded.

In this technoscape humans are fallible and machines are needed as mediators between the nanoworld and the researchers since the nanoworld is beyond human immediate sensory experience. Technology becomes an extension of the human body and the fallible researchers are enabled to achieve objectivity through the use of machines as the readouts from them are supposed to report true nature. The separation between objective/subjective and universal/local is taken to its extreme in the cleanroom which is a landscape in which influences from the subjective extramural local surroundings are minimized to allow for the exploration of true nature. In the cleanroom human subjectivity needs to be directly controlled since individual expressions such as strong emotions, smoking and hasty body movements may endanger experiments.

In a similar manner, among the researchers there is an ambition to transform subjective individual skills to depersonalized skills that can be generalized and applied irrespective of agent, time and place. Personal skills are commonly entangled in everyday practice and they are often associated with subjective and highly individual gut feelings of how to behave for realizing experiments successfully. These gut feelings are subjective and tied to specific researchers. By quantifying the various steps of experiments individual skills are depersonalized and gut feelings are transformed into numbers, diagrams and ultimately into articles that make individual experiments repeatable by other researchers.

Ludwig von Bertalanffy (1955: 258) argued in 1955 that an essential part of science was a progressive de-anthropomorphization in which elements belonging to individual human experiences were to be eliminated. Also Ingold (1993: 224) argues that science signifies a progressive de-anthropomorphization of the world in which phenomena are reduced to matter and energy. The objectivistic aim to get rid of human influences is explicit when entering the cleanroom. The strict regulations of how to behave serve to diminish the expression of individual characteristics as they hinder personal articulations, such as waving ones' arms about or talking loudly when exited, as well as hindering the satisfaction of individual urges such as the desire to smoke. Putting on the cleanroom dress requires the removal of personalizing items such as cosmetics, rings and wristwatches. The use of full body suits in the cleanroom results in imposed uniformity which makes it hard to identify individuals and creates a collective of similar looking peers. The ideal is for researchers to coolly register the structures and processes of the experiments they pursue and turn their actions into mechanically operating automations that are minimally influenced by their human nature.

Traweek (1988) suggests the term "culture of no culture" to describe a community of high-energy physicists. She wants to describe a culture of extreme objectivity in which the scientists conceive of themselves as free from their own preconceptions when conducting research. I would argue that the "culture of no culture" among researchers at MC2 is based on a strong notion of individualism in which intramural scientific individuals are only distinguished by their various personal skills. By arguing that only personal skills are valued, cultural traits are removed, making nationality, class, political views, religion etc, irrelevant. Culture, from the perspective of the researcher, is associated with markers of the extramural non-scientific "other" in being an aspect of humanness that ideally is no part of science. From a perceived common non-cultural scientific stance the researchers conceive of themselves as being in a position from which they can produce universalistic valid knowledge about the world. Accordingly, the idea is that by reducing the subject to a minimum, objectivity is reached and, at the same time, researchers' individuality is reduced to "next to nothing."

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