

DEDICATION

To my Print Master, my loving husband
Matthew Paul Knefel

ACKNOWLEDGEMENTS

A dissertation is not the outcome of the efforts of entirely one individual. Many people have contributed to its development. At this time, I take the opportunity to acknowledge those who have made some impact on my doctoral journey and accomplishment. First and foremost, I thank God for the numerous blessings He has bestowed upon me throughout my dissertation journey.

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FOREWORD

Growing up in the Caribbean, I felt as if my family expected me to be either a lawyer or a doctor. So, I started high school with the intention of becoming a doctor. This meant tailoring my academic interests to follow natural science subjects: Biology, Chemistry, and Physics, that were traditionally seen as male territory and culturally perceived as dominated by individuals of East Indian descent. As a black female, the odds seemed stacked against me. Initially, I felt up to the challenge. I started out by attempting to become an avid viewer of the drama series *St. Elsewhere* – a television show that depicted the lives and work of doctors and their patients. But, I soon realized that I cringed at the sight of blood, and did not have the general constitution for what it took to be a *St. Elsewhere* doctor. Besides, I had heard the horror stories about having to dissect frogs and rats in the school’s laboratory, and decided that no matter how prestigious and lucrative a career in the sciences appeared, it was not for me. I turned my heels on the sciences and lunged forward into the humanities – Literature, History and later, Sociology.

In contrast to myself, my best friend pursued biochemistry. To her, science was interesting, thrilling and a worthy endeavor. To me, it seemed time-consuming, unappealing, and too abstracted from the individual, everyday problems of life. At the time, it all seemed like numbers, formulas, calculations and technical jargon to me. While part of me felt like Ebenezer Scrooge, it was all “humbug,” a part of me was awestruck and fascinated by the multitude of discoveries and advancements science could yield. It would be several years later before my thoughts and feelings about science would resurface. While pursuing my doctorate in Sociology, I took a class in Science

and Technology Studies (STS). At first, I was intrigued because I wondered what a sociologist could possibly have to say on a subject that formerly seemed so elusive and grandiose to me.

It was in this class that I began to see that my best friend's scientific practice was indeed no different from my own sociological work. Furthermore, the scientific content, methods and theories of her work, I learnt, develop within a socially and culturally situated context that made the scientific endeavor seem to me more like guesswork – a patchwork built upon the scientist's ability to craft ostensibly value-free interpretations from his or her own subjective observations. I, therefore, began to wonder again and anew what exactly is the nature of science, what are the roots of the supposed objectivity in science, what are the contexts involved in the production of scientific knowledge and how do our conceptions of science affect us at the mundane level of our existence. But, as all good things come to an end, I ended my class that semester with the settled feeling that most of my questions were resolved and I could now move on to other interests.

Nevertheless, it would not be long before the opportunity to delve deeper into those questions would present itself in a most unlikely fashion. In the spring of 2002, while attending a collaborative meeting with my departmental chair, one of my Sociology professors and a professor from the Geosciences department, the word “nanotechnology”¹ was first mentioned. I remember sitting there in a panic as the word kept popping up in the conversation. Not wishing to reveal my obvious ignorance, I waited until the meeting was over to approach the geoscientist to find out what nanotechnology meant. She kindly explained and I feigned interest when I realized that it had something to do with molecules, control, physics, engineering, etc.

I became excited when I discovered that she was a program director on an upcoming National Science Foundation (NSF) funded project that would be attempting to bring together nanoscientists in the Geology department and teachers from surrounding high schools in the area to develop nanotechnology curriculum in a series of summer workshops. And, she was looking for an external evaluator for the project. Upon the advice of a Sociology professor, I decided that this would be a great opportunity to develop some skills in evaluation research and so, we discussed it with the program director who agreed to employ me over the summer as the program evaluator. Still, I did not see the potential of my involvement as an evaluator until the suggestion was made by the program director that any interested Sociology student could use the workshops for his or her dissertation.

My earlier questions about science and technology came flooding back and I thought that this would be a great opportunity to, not only pry into such questions myself, but to complete my doctoral journey in a timely and cost effective manner. Thus, I took on the dual role of paid evaluator and social researcher, delving into the issues about the construction and production of scientific knowledge that had formerly plagued me. I wanted to know first and foremost, what was nanotechnology – its nature and context; why was it fast becoming common verbiage among some scientists, prominent business leaders and government officials; how was it being constituted; what connection, if any, did these summer workshops held on my college campus have to the larger context of nanotechnology; how was the workshop – this nanoscientist-teacher collaboration – to be achieved; what types of knowledge would they be producing; and how were they going to

effectively turn their workshops into practical tools for high school students? And so my journey into nanotechnology began in the summer of 2002.

¹ I refer to nanotechnology rather than nanoscience since this was how it was first introduced to me, but the terms are habitually used interchangeably.

Chapter One: INTRODUCTION

We live and work in an age of remarkable scientific discoveries and applications that power and sustain virtually every facet of our lives. In his book entitled *Nanotechnology: Molecular Speculations on Global Abundance*, B.C. Crandall¹ (1996) claims that we are standing at the “threshold of a molecular dawn” – a dawn exemplified in the emergence of a new science called nanotechnology. Also referred to as nanoscience, it is called nanotechnology because simple molecular components are measured in nanometers, or billionths of a meter (Regis 1995).

Because it is new and exciting, nanotechnology has captured the attention of governments and corporations around the globe. It has become the subject and context for numerous conferences, media articles, websites and scientific research papers. Nano enthusiasts and government officials claim that it is an area that promises new understandings of nature, and use of that understanding to build technologies that might change our lives (Drexler 2002; Gross 1999; DuCharme, 1995).

Despite the growing hype, what appears to be lacking is scholarly literature that examines nanotechnology’s growth and expansion from a social science perspective. This study addressed this limitation with the hope of increasing understanding and dialogue about an area that is fast becoming the “new big thing” in science.

Statement of the Problem

Science is considered the prototype of rationale modes of knowing, knowledge formation and validation. However, for more than two decades, social constructivist views of the nature of scientific knowledge, promoted within the field of the sociology of scientific knowledge (SSK), have emphasized that even the “content” of scientific

knowledge can be examined sociologically (Gittler 1940; Bloor 1976; Knorr-Cetina and Mulkay 1983; Zuckerman 1988; Longino 1990). Numerous ethnographic studies of science have concluded that what scientists do is not fundamentally different from what other researchers do (Latour and Woolgar 1986; Latour 1987; Traweek 1988; Pickering 1995). Social research in science and technology has also pointed to the social nature of scientific knowledge making processes, noting that they can and are influenced by the context – social, cultural, political and economic – in which scientific work is performed.

In the nascent area of nanotechnology, this appears to be no different. One of the hopes of nanoscience and technology is that the combination of a number of areas – from biology to computer science – might lead to major advances in understanding and applying science in technology. What we are seeing through nanotechnology's multidisciplinary approach is a new condition in scientific knowledge formation. Both the traditional disciplinary boundaries and the boundaries of research laboratories are becoming increasingly permeable. In nanotechnology, new actors from various sectors, including industry, education, politics and administration are being integrated into its knowledge making and validating processes.

In general, several scholars have already investigated the processes, practices, and artifacts of knowledge production (Knorr-Cetina 1981; Gilbert and Mulkay 1984; Keller 1985; Callon 1986; Bijker and Pinch 1987; Latour 1987; Traweek 1988; Longino 1990; Halfpenny 1991; Haraway 1991; Shapin 1995), and continue to investigate the social relations within and between scientific communities and their social, economic and institutional contexts. I have found the works of Callon, Latour, Longino and Traweek to be particularly relevant to my study. They emphasized the “indexical and contextually

contingent properties” (Knorr-Cetina 1981) of science, investigated scientific practice at the site of knowledge production – the laboratory, and explored the effects of social, economic, political and professional interests on the content of science. In so doing, they have shown that scientific knowledge is the product of a social group – a network of human and nonhuman actors (Latour 1987) and therefore, a social activity.

The purpose of this case study was to describe and analyze this network of actors, events, rhetorical strategies, practices and instrumentation that go into the construction and growth of this “new science” – nanotechnology. More precisely, I examined a small part of the total network – the knowledge education production process, which involved the enrolment of high school teachers into the nanotechnology network through a series of collaborative workshops – the Nanotechnology Curriculum Development Project (NCDP) – with Virginia Polytechnic and State University (Virginia Tech) scientists over a period of two years. Specifically, when I refer to the term “knowledge,” I am not talking about what the scientists themselves are doing in the labs, that is, knowledge at the frontier of science. Rather, I am referring to “knowledge education production,” that is, the transfer of the scientists’ knowledge about nanotechnology to high school teachers.

This study was guided by the following research questions:

- What actors were enrolled in the nanotechnology network?
- What actors’ interests and motivations influenced their enrolment in the network?
- What internal factors affected the network?
- What external factors affected the network?

Significance of the Study

This study is important for a number of reasons. First, this research relied heavily on the actor-network theory (ANT) within the SSK framework, which emphasizes the day-to-day practices of scientists. However, rather than focusing on scientific practice at the site of production – the laboratory, this study addresses the question of whether or not ANT applies to the specific techno-scientific enterprise of nanotechnology as it moves beyond the laboratory into public arenas such as high schools. In this regard, this study is unique because it looks at the intermediary role of high school science and math teachers in the construction and growth of scientific networks. As high school teachers exist within two domains – science and science education, this study sheds light on this interface and the function of teachers as focal actors enabling nanotechnology to move from the laboratory into public awareness.

Second, this study attempts to address a major criticism of ANT, that is, its failure to adequately explain the social contexts, structures and processes that constitute scientific networks and its growth. Also, although ANT does acknowledge the possibility of resistance in scientific networks, it does not go far enough in identifying or explaining the social elements that bring about resistance among and between actor networks. Because this study focuses on the roles of conflict, power, authority, hierarchy, interests, motivations, gender and race in scientific network construction and expansion, as well as the notion that there can be internal and external factors of conflict (i.e. resistance), it allows for a substantial contribution to advancing knowledge in the sociology of science and technology.

Finally, as I noted earlier, there is a general paucity of sociological inquiry into the field of nanotechnology. This is particularly interesting considering the projections that nanotechnology has the potential to affect all social systems – industry, home, health, entertainment, etc. – as they currently exist. Therefore, the context of nanotechnology itself provides a unique opportunity to develop our understanding of how technical and social systems affect one another.

¹ B.C. Crandall is the founder and director of Molecular Realities and the founder and president of Memetic Engineering. He is also the cofounder of Prime Arithmetics, Inc. He edited the proceedings of the first international conference on nanotechnology called *Nanotechnology: Research and Perspectives*, which was published by The MIT Press in 1992.

Chapter Two : LITERATURE REVIEW

This chapter contains a review of the literature relevant to this case study. In it, I describe the context of this study – nanotechnology – and the various tools, techniques and ways in which its growth is becoming stabilized or legitimized. I also identify and explain the body of sociological work and the specific theoretical perspective I adopted, as well as the various ways in which scientific networks have been studied within the relevant theoretical framework of the sociology of scientific knowledge (SSK). See Appendix F for list of acronyms used in this study.

The Nanotechnology Context

Several studies, particularly feminist and environmentalist critiques of science have documented the evolution of our changing interpretations in human/nature relations (Williams 1972; Merchant 1982; Schama 1995; Short 1991; Thomas 1984). Such works indicate that as our civilization evolved, our view of nature also changed. According to Macnaghten and Urry (1998), we adopted a doctrine of “human exceptionalism” that holds humans to be fundamentally different from and superior to all other species.

This has not always been the case. For example, the ancient Greeks saw humans and nature in a state of balance and harmony. However, during the 16th and 17th centuries, through the new sciences of physics, astronomy and mathematics, nature became “a set of laws, cases and conventions, discoverable through the new rules of inquiry; forms of inquiry which could be carried out in their own terms without any recourse to a divine purpose or design” (Macnaghten and Urry 1998). Modern science, embodied in the writings of Francis Bacon held to an idea of man’s dominion over nature as a strong component of its formation.

It is not necessary to provide a copious explanation for how or why this came to be as this is not the focus of this case study. However, Keller (1985) and Merchant (1982) are helpful in providing us with some insight here. For instance, Keller, using a psychodynamic analysis explained that conflicts in men over masculinity create a psychology of male dominance. It followed therefore that as most scientists are men, this male mind set of dominance and control, obsessed with detachment and mastery, becomes written into the norms and methods of modern science. Merchant, however, using a sociological approach, contended that this dominion is not a necessary part of science, but rather arose in order to reinforce societal sympathy towards the principles of progress and early capitalism. In other words, “modernity involved the belief that human progress should be measured and evaluated in terms of the domination of nature...” (Macnaghten and Urry 1998: 7).

Two decades ago, Marcuse (1964: 158) in his work entitled *One Dimensional Man* wrote that “the principles of modern science were a priori structured in such a way that they could serve as conceptual instruments for a universe of self-propelling productive control.” This led him to believe that part of the objective of science is “domination of nature.” Today, I agree that not much has changed. In fact, with the recent emergence of new areas and projects in science like genetic engineering, biotechnology, robotics, cloning, cyberintelligence, the Human Genome, this scientific scrutiny into the natural world seems to have intensified. Beginning in the 1990s, there has been a major buzz surrounding a relatively new field in science: nanotechnology, which appears as yet another arena that enables scientists and technologists to dominate natural phenomena. Simply put, it is the science of manipulating and controlling matter

at the atomic and molecular level to build desired structures and to create novel forms of common materials (DuCharme 1995; Ebisch 2003; Teschler 2000; Lewis 2001; Feder 2003).

Furthermore, Gross (1999: 199) identifies three essential components of nanotechnology. The first is that it involves molecular manufacturing, that is, products can be assembled on the nanometer scale with extreme precision allowing the rearrangement of individual atoms and molecules. The second introduces the use of materials with novel and/or adaptable properties, controllable by molecular manufacturing. And finally, it involves the miniaturization of electronic and mechanical parts down to the atomic scale, leading to nanomachines, whose compactness and efficiency could even outperform the cellular systems. K. Eric Drexler, the prophet and guru of nanotechnology defines it as the “thorough, inexpensive control of the structure of matter based on molecule-by-molecule control of products and byproducts; the products and processes of molecular manufacturing” (Drexler 2002: 2).

Nanotechnology is not an entirely new field of study, but within the last two decades, nano enthusiasts, science experts and government officials have all hailed it as one of the most exciting fields of science (Sweeney, Seal and Vaidyanathan 2003; The House Committee on Science Hearings 2003). What is special about nanotechnology? The National Science and Technology Council’s (Amato 1999: 4) official brochure entitled *Nanotechnology, Shaping the World Atom by Atom*, declares that it “stands out as a likely launch pad to a new technological era because it focuses on perhaps the final engineering scales people have yet to master.” Because it measures molecular

components in nanometers, it has given researchers an entirely new perspective on how matter acts (Salkever 1999).

According to Feynman in Appenzeller 1991, “when we get to the very, very small world...we have a lot of new things that would happen that represent completely new opportunities for design. Atoms on a small scale behave like nothing on a large scale, they satisfy the laws of quantum mechanics.” Thus, one of its benefits is that materials and structures exhibit new electrical, mechanical, thermal, optical and chemical properties at the nanoscale. Theoretically then, one day we will be able to rearrange materials at the atomic level to create almost anything we want (Belsie 2000): better computers, medical diagnostic tools and chemical sensors, among other things. It is this small scale – the ability to put molecules and atoms to new uses (Freedman 1991: 1308) – that fuels the hope and hype surrounding nanotechnology.

Until a few years ago, nanotechnology was considered science fiction. However, the last 25 years have witnessed astonishing advances in several fields because of nanotechnology (Heath et. al 1998: 1716). The production of nanoparticles by a number of established companies is already laying the groundwork for the rapid growth in nanotechnology. Some examples include cerium and indium oxides for the coatings, electronics, personal care and optics industry among a wide range of potential products focused on nano-structured water-repellent coatings (The Advanced SemiConductor Magazine 2003). When it comes to supercomputing power, nanotechnology is already the enabler of chips no bigger than a grain of sand that fit into birthday cards with popular musical greetings and into operational electronic digital (super) computers (Teresko 2001). According to Fairley (2001), chemical companies and entrepreneurs are

leading efforts to mass-produce nanomaterials, including the carbon spheres known as fullerenes. Among the many applications under development are the use of these fullerenes as a skin-protecting scavenger in cosmetics; an electron source for next-generation flat-panel computer displays and TVs; and a hydrogen-absorbing fuel storage matrix for fuel-cell cars.

Probably the most visible nanotechnology product to date are the stain and wrinkle resistant slacks developed by Nano-Tex and sold by Eddie Bauer, Lee Jeans and several other retailers (CNN.com 2003). Despite such sparse advancements in the field, officials and experts continue to promote nanotechnology as a revolutionary moment in society and foster considerable excitement about and acceptance of nanotechnology as a legitimate field of study worthy of scientific pursuit and of government and private industry funding. Furthermore, Nordmann (2003:1) asserts that “there is no shared problem at the heart of nanoscale research.” It is a science not driven by theoretical questions or overarching problems like cancer or artificial intelligence. “The enormous level of government funding is not associated with any specific promise, no public expectation or political justification. Instead, what we get is a ‘sweeping claim’” that promises more than it can actually offer.

If this is the reality of nanotechnology, that it is still nebulous at best, the key question becomes: how are nanoscientists and experts able to convince politicians of its “potentials”? How do these actors go about enrolling supporters into the nanotechnology network and discrediting dissenters? What tools, strategies and resources are being mobilized to legitimize or gain credibility for the continued pursuit of scientific research and growth in this field?

Legitimizing Scientific Claims in Nanotechnology

According to Epstein (1995:411), when we talk about scientific legitimacy or credibility, what we are talking about is “the capacity of claims makers to enrol supporters behind their claims, to legitimate their arguments as authoritative knowledge and to present themselves as the sort of people who can give voice to science.” Citing Weber (1978: 212-254), Epstein adds that in a Weberian sense, scientific credibility can be considered a system of authority, combining aspects of power, dependence, legitimation, trust and persuasion. In his Congressional testimony at the House Committee on Science Hearings on “The Societal Implications of Nanotechnology,” Langdon Winner (2003) paints a useful picture of this activity by showing what typically occurs once a new technology is proposed and what factors and strategies go into its acceptance or rejection as claims makers seek to enrol supporters, to gain and maintain scientific credibility and legitimacy.

What happens is that the promoters of a new technology, those with the most to gain in the short run, are the ones who speak first and most loudly. The boosters predict a wide range of practical benefits – new products, services, efficiencies, improvements of all kind. Indeed, they usually proclaim that there is a revolution just around the corner, one that will alter society for the better, making us wealthier, wiser, more democratic, and stronger in community bonds. Promoters try a clever ploy announcing that the changes on the horizon are “inevitable.”..The acceptance of any technology requires the building of a broad social coalition that agrees to support its introduction and use. The test of whether or not a technology is acceptable is ultimately whether enough people agree that “yes, the new methods make sense.” The failure to provide open, thorough and honest attention to the broader social, political, and cultural contexts that influence the acceptance or rejection of emerging technologies can lead to disaster, for example, the crisis now surrounding biotechnology. I do know that it is increasingly risky to ignore or exclude the great multiplicity of groups and interests that would like to have a voice in defining what these technologies are and what they mean.

This description can be effectively applied to the growth of nanotechnology as it reveals several important strategies and components involved in building scientific legitimacy:

rhetorical claims, public policy formation and coalition building around various interests that may include businesses, universities, corporations, governments, and so on.

Several studies in the science studies (STS) have already explored the ways in which science and its claims, in general, become legitimized (Rorty 1991; Bourdieu 1975; Shapin 1988; Lyotard 1984). For instance, Bourdieu (1975) noted that science is the “locus of a competitive struggle” in which the specific issue at stake is the monopoly of scientific authority or legitimacy; the latter being a particular kind of capital that can be accumulated, transmitted and redefined. Thus, strategies, tools and resources to achieve or maintain legitimacy are important in science. In addition, the focus of many STS studies has been the constitution of knowledge claims (Leydesdorff 1991). Such studies (Bijker 1987; Bijker and Pinch 1987; Latour 1996; Sorensen and Levold 1992) show that legitimizing claims in science is not simply achieved by a special breed of scientists who draw on established knowledge and practical skills to solve problems, but it involves “networks of sociotechnical relations in which interpretations of social, scientific and technological facts and artifacts compete for acceptance and domination” (Roth, McGinn and Bowen 1996).

Some studies have also highlighted that relationships with funding agencies, other researchers, those in charge at research sites and the public are important to the acceptance or rejection of technology and knowledge claims. Still, others demonstrated that rhetoric (Collins and Pinch 1982; Pickering 1981; Pinch 1986; Latour 1987) is often adopted as a tool of persuasion to convince others to accept scientific claims. Fountain (1999: 346) referring to Latour’s work, also pointed out that texts – scientific journals and articles – have “far greater importance as a political tool for the scientist-

entrepreneur.” Consistent with these findings, I identified several strategies, tools and mechanisms by which nanotechnology is becoming legitimized: scientific expertise, inscription devices, rhetorical claims, markets, funding, policy and coalition building.

Scientific Expertise

Citing Mannheim’s *Ideology and Utopia*, Gittler (1940: 357) remarked:

...The sociology of knowledge is concerned with the persons who are the bearers of intellectual activity namely the intellectuals. In every society there are individuals whose special function it is to accumulate, preserve, reformulate, and disseminate the intellectual heritage of the group. The composition of this group, their social derivation and the method by which they are recruited, their organization, their class affiliation, the rewards and prestige they receive, their participation in other spheres of social life, constitute some of the more crucial questions to which the sociology of knowledge seeks answers.

To the extent that the intellectuals as a group furnish vital problems to the sociology of knowledge, the role of the science expert becomes an important source of study in the sociology of scientific knowledge (SSK). The science expert whose position was traditionally perceived as impersonal, value-free and objective has often been used to solidify and defend decisions to accept or reject a new scientific idea or technological innovation, not based on purely scientific factors, but rather on the basis of economic and political issues (Dickson 1984).

For nanotechnology to work, “you need more and more people dedicated to this kind of pursuit” (Hartill 2001). Thus, we may infer that one of the most important tools determining how nanotechnology is becoming legitimized is the people – the array of scientific expertise, that is, those involved in producing and maintaining knowledge about nanotechnology. Scientific expertise in nanotechnology is by no means confined to lab-coat scientists in university centers and facilities involved in the molecular manipulation for as Epstein (1995) noted negotiations over credibility are multilateral: they may

involve many different players. These players help determine who is credible, which knowledge claims are credible, and which ways of doing research are credible. In nanotechnology, scientific expertise also involves the enrolment of an entire field of visionary prophet[s] or intellectuals and their disciples that herald its praises far and wide – from key individuals and commentators in the field, professional science and engineering communities, corporate research labs to government-funding institutes and centers.

Although nanotechnology is a new word, the idea has been percolating since 1959 when Nobel Laureate Richard Feynman, nanotechnology's first "Nostrodamus" and one of the century's most admired physicists, gave a speech at Caltech entitled "There's Plenty of Room at the Bottom"¹. In it, he argued that "the principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom," and he described concepts for tiny computers and nanorobots to manufacture materials and intelligent machines that could perform surgery once swallowed (Spotts 1999; Thompson 2000). Near the end of his talk, Feynman posed the ultimate challenge of matter when he said: "I am not afraid to consider the final question. Can (we) arrange atoms the way we want, all the way down"? The general reaction to his comments was amusement. Most of the audience thought he was trying to be funny (Appenzeller 1991).

Thus, Feynman's idea lay dormant until 1981, when a 26-year-old graduate student from Massachusetts Institute of Technology (MIT) named K. Eric Drexler published a paper in the Proceedings of the National Academy of Sciences titled "Molecular Engineering: An Approach to the Development of General Capabilities for Molecular Manipulation." Essentially, he took strands from separate science areas like

chemistry, genetic engineering, physics and computer science and wove them into a single new strand, which he called nanotechnology. Since then, Drexler, the second prophet, has dedicated his life, heart, and soul to telling people about the potential benefits of nanotechnology.

Although Feynman is credited with founding nanotechnology (Morrow 2000: 29), Drexler's tireless promotion of what he describes as a "prophet perspective" has turned him into "Mr. Nanotechnology" at least in the public eye. By writing a continual stream of books, encyclopedia articles and technical papers, spawning nanotechnology study groups at universities, giving dozens of lectures around the world and speaking to Congress, he has probably done more to raise public consciousness about nanotechnology possibilities than any other scientists (Freedman 1991). The gospel of nanotechnology is also preached by his wife, Chris Peterson, who runs the Foresight Institute they set up as a nanotechnology clearinghouse (Rogers and Kaplan 1997/98).

Despite criticism regarding his "utopianizing" nanotechnology's potential benefits, while glossing over its risks and problems, Drexler is not without his followers or disciples. Popular commentators in the field include Ray Kurzweil who is considered a pioneer in artificial intelligence; Ralph Merkle of Xerox's Palo Alto Research Center; and Richard Smalley, a Nobel-prize winning chemist and the director of Rice University's Center for Nanoscale Science and Technology (Rogers and Kaplan 1997/98; Thompson 2000). Another is Wesley DuCharme (1995) whose book *Becoming Immortal: Nanotechnology, You, and the Demise of Death*, dedicated to showing how nanotechnology can lead to physical immortality. Supporters can also be found among corporate tycoons like Von Ehr, a 50 year old software minimogul who spent \$14 million

of his \$200 million fortune funding a company called Zyvex. He hopes to be the first entrepreneur to start selling submicroscopic robots and reasons that “if nature can make these machines, man can at least come close. And if there’s money to be made in it, humans will eventually figure out a way... Having a lot of money has allowed me to do something bigger than I could have otherwise” (Fahley 2001: 1-3)

Moreover, the task of legitimizing nanotechnology is evidenced by the proliferation of an increasing number of institutes, research programs and laboratories around the world with names related to the issue. There are several nanotechnology centers in Japan, a “Nano-Valley” in the Upper Rhine involving both German and French institutes and universities, and the “Nanotechnology Link Programme” in Britain. In Germany, the minister of education, science, research and technology, Jurgen Ruttgers, announced plans to create five new nanotechnology centers. In the United States (U.S.), there is the “Cornell Nanofabrication Facility” (formerly the “National Nanofabrication Facility”), which is a fully equipped nanotechnology workshop that caters to visiting researchers from around the country (Amato 1991).

Nanotechnology has its foot planted in academia and business. Georgia Tech announced plans to build an \$80 million nanotechnology research center, which will serve approximately 1000 undergraduate and graduate students. Only about a half dozen universities across the country have similar nanotechnology research centers under development, including MIT, Stanford and Cornell. Scientists and groups at several other universities (Harvard University, Pennsylvania State University, the University of Michigan, Rensselaer Polytechnic Institute in New York, the University of California at Berkeley and so on) as well as researchers at business centers (Hewlett Packard, IBM

Corporation, Mitre Corporation, Bucky USA, Nanophase, NanoBusiness Alliance and Allegheny Ludlum Steel's Technical Center) are all working to design new processes and techniques that will fulfill nanotechnology ideas and claims (Teresko 2001; Wang 2001; Miner 2001; Teschler 2000; Kalb 1999/2000; McGuinness 1997; Weiss 2001; Thompson 2000; Salkever 1999; Crenson 1994).

Nanotechnology is also part of the techno culture of Silicon Valley – one of the triumphant gateways into computing's future. The Valley crowd makes nanotechnology a hot discussion topic on favored technology Web sites like Slashdot and magazines like Wired (Thompson 2000). In addition, there is an Institute for Molecular Manufacturing which funds nanotechnology research, a think tank based in Palo Alto, California (The Futurist 1998) and The Foresight Institute (nanotechnology's political center), founded by Eric Drexler and devoted to promoting the understanding of nanotechnology and its effects through its website (<http://www.foresight.org>) and annual symposium. The role of these centers in expanding the nanotechnology network and bringing credibility to the field is important as Latour's (1988) study of Pasteur's work on anthrax showed that they can be used as levers to persuade others to support the work being conducted therein and hence, are powerful sources of political strength.

Inscription Devices

According to Leydesdorff (1991: 75), "science has become a mass-production process of scientific knowledge in the form of articles, reviews, and books. This sedimentation of knowledge is organized at various levels of aggregation: at the very base there are words and combinations of words. Sentences are organized in paragraphs and sections, which sequence the line of argument within an article. Articles contain the

unit contributions (“knowledge claims”) of scientific development and form ensembles which constitute volumes of journals, archives of specialties and eventually disciplines.” The beginning of nanotechnology as an established research discipline is evidenced by just that: “a mass-production of scientific knowledge”; a key mechanism powering nanotechnology’s goal toward scientific credibility.

Recently, we have witnessed a significant increase in the number of research papers being produced in this field (Gross 1999). New articles continue to appear almost monthly in leading scientific journals and university research departments are starting to fill with enthusiasts (Thompson 2000). Several journals and websites have been developed and various national and international conferences have been held. One of the most recent was the “NanoFinancing 2002” conference, arranged and promoted by the Strategic Research Institute to address market capitalization in the nanotechnology industry. Held in March 2002 in Los Angeles, California, the main goal of this investor conference was to offer a forum where new entrants could learn from pioneers in the field including technology leaders, corporate investors, venture capitalists, government sponsors and lab researchers.

Legitimizing nanotechnology not only involves the enrolment of inscription devices used solely in science such as the scientific journals, books, articles. It also includes devices employed by others in completely different arenas but which can have the indirect effect of enrolling supporters around its claims. For instance, though less identifiable as nanotechnology to the public, it is being legitimized through the mass-production of knowledge disseminated in movies (The Matrix, Minority Report, Johnny Mnemonic, to name a few) and science fiction novels.

Personally, I recall sitting in a movie theater room, waiting anxiously to get a glimpse of some really cool special effects, when within the first 15 minutes into the “Spiderman” movie, actor Tobey MaGuire who played the role of Peter Parker said that he just completed a school paper on nanotechnology. The plot focused heavily on a villain who was both the creator and host of a molecular manipulation – the essential premise of nanotechnology – gone array. Similarly, in November 2002, Michael Crichton, published *Prey*, a science fiction novel in which self-replicating, intelligent and rapidly evolving nanoscale robots posed a mortal threat to humans and to the environment. And, Greg Egan’s (1994) science fiction novel *Quarantine* featured a neural nano mod – a microscopic computer application delivered nasally, allowing a minute workstation to be contained in the hero’s brain (The Computer Bulletin 2003).

An inscription device can also be a machine, a microscope or a computer – anything that renders representation to nature. According to Latour (1987) through the use of such devices, scientists and engineers strengthen their own positions. In the last few years, scientists have come up with one important innovation after another, and science fiction has gradually been moving into science fact. Although researchers say that most practical objects are still decades away, increasingly complex experiments show progress toward fabricating objects at the molecular level. For example, Brian Hubert, a doctoral candidate in mechanical engineering at MIT recently invented a Nano Assembly Machine that can, with a tip the size of a human hair, dip into a reservoir of any material, (polymers, metals,) and quickly assemble several nanostructures, thousands of atoms at a time (Hartill 2001).

The windows into the nanoworld have been opened by several inscription devices and techniques. The actual realization of nanotechnology was brought about in the 1980s through the development of scanning probe methods that allow visualization and later manipulation of very small objects, down to individual molecules (Gimzewski in Morrow 2002). Scanning probe microscopies map molecules deposited on a surface, as well as deposit individual atoms and molecules in desired patterns (Teschler 2000; Rogers and Kaplan 1997/98). The invention of electron microscopy (Salkever 1999), X-ray crystallography, neutron scattering and nuclear magnetic resources now allow researchers striving for greater control to “see” at the nanoscale (Fairley 2001). Both invented in Switzerland, the scanning tunneling microscopy (STM) and the atomic force microscopy (AFM) also enable nanoscientists to produce knowledge at the nanoscale and thereby, legitimize their claims.

Rhetorical Claims

When science declares an interest in something new, something intriguing happens: “we sometimes find unusually explicit claims about the scope and applicability of the science, about its ability to transcend established boundaries, and about its relevance for the new domain... These programmatic discussions [i.e. the rhetoric] are revealing, because they often include representations of the form and structure of argument (and explanation) that characterize that science” (Woolgar 1991: 20). Nanotechnology, as the “something new” provides a useful site for learning more about the rhetoric that sustains it.

In nanotechnology, rhetoric is one of the tools employed to persuade, convince and ultimately enrol supporters. I should also stress that rhetoric is not built on entirely

new discourses, ideas and assumptions as Gottweis (1998) argued that it is built up on layers of previous discourse. As we shall see, rhetorical claims draw upon a mixture of existing values, ideas, assumptions and ideological themes [e.g. ‘inevitability of progress’, ‘endless frontier’, ‘competitiveness crisis’ and ‘social utility’] long espoused in science and technology. Scientists, engineers and policy makers call upon such themes in their efforts to bring legitimacy to the field. Below, I provide some evidence from policy documents, journal articles, magazines and books of such themes in the nanotechnology rhetoric.

Inevitability of Progress

As stated by Hannah Arendt (1969: 25), “the notion that there is such a thing as Progress of mankind as a whole was unknown prior to the eighteenth century and became an almost universally accepted dogma in the nineteenth century.” However, some scholars (Nisbet 1980) contend that the idea of progress existed long before this period, in classical and medieval times. Regardless of such debates, it is clear that today, the myth of progress, moreover the ‘inevitability of progress’, is considered a primary feature of Western civilization and American society, in particular. Perhaps, nowhere is the myth most espoused than in the field of science and technology. Based on an acceptance of economic and technological growth and a faith in reason, science and scholarly knowledge as key premises of progress, the latter implies that scientific endeavors and technological pursuits are neutral and beneficent. This leads us, as Dickson (1974: 183) observed, to accept techno-scientific developments and innovations as “being a unique, inevitable, and politically neutral process.”

Recent research has shown that progress is deeply embedded in institutions, communities and networks that shape the choice and path of particular ideas (Murray 2002; Almeida and Kogut 1999; Bijker, Hughes and Pinch 1987; Blume 1992; McKelvey 1997). It is a theme capitalized on in the nanotechnology rhetoric to convince others of the field's credibility as a discipline worth pursuing. The following are but a few samples taken from journal articles, magazines, books and policy documents that reflect the 'inevitability of progress' theme² in nanotechnology claims:

B. C. Crandall Transcript:

"Our future is molecular because if we do not take molecular care we will not be materially alive, and that brings all our fine conversations - political, philosophical, spiritual, economic - to a graceless halt. In the next few decades, with the development of nanotechnology, a window of opportunity will open, during which we will be able to use early applications of molecularly engineered materials to launch a multitude of substantial, ecologically self-sustaining - and primate supporting - ecosystems into the previously untenable ecological niche of space" (Kroker and Kroker 1996)

The Computer Bulletin:

According to the Northern California Nanotechnology Initiative (NCNI), there is a growing view that nanotechnology will play a critical role in the US economy and in society, comparing its potential impact over the next 20 years to that of the steam engine, electricity, antibiotics, the computer and the internet. The NCNI says that the contents of the US Library of Congress could be stored in a device the size of a sugar cube (July 2003: 32).

Travels to the Nanoworld: Miniature Machinery in Nature and Technology:

"... [the] world population of more than 10 billion people will ... leave all limits to growth behind and live in unbelievable wealth" (Gross 1999: 192).

Despite inadequate empirical connections between science-technology and progress on an industrial and intellectual scale, rhetorical claims in nanotechnology seem to be structured around such conventional frameworks that treat science and technology as synonymous with intellectual progress and material progress, respectively. The excerpts show that nanotechnology is growing and becoming legitimized in part through explicit rhetoric based on the inevitability of progress.

Endless Frontier

In my talks with nanoscientists, as well as my review of the literature, I have observed that perhaps, one of the most prominent and frequently referenced phrases to describe nanotechnology is ‘cutting edge’, synonymous with the term ‘frontier’. The ‘endless frontier’ rhetoric depicts nanotechnology as thrilling and powerful, and its promised applications as limitless: nanotechnology knows no bounds, “limited only by our imaginations” (Lewis 2001).

The Promises and Perils of Nanoscience and Nanotechnology

Nanotechnology research is leading science into exciting and unknown frontiers in the new millennium (Sweeney, Seal and Vaidyanathan 2003: 236).

Shaping Policy for Nanotechnology Development

Nanoscience and Nanotechnology stand as the next great frontiers for exploration and conquest – perhaps the greatest frontiers we’ve ever faced...” (Speech given by Assistant Secretary for Technology Policy at the University of California, Bruce P. Mehlman in September 2001).

Newsweek

Playing games in the nanoworld holds the Promethean promise of giving society any material it wants at virtually no cost--500-story skyscrapers made from diamond rather than steel, fabulously powerful microprocessors, spaceships that have the strength of titanium but the weight of plastic, paint that changes color, "smart" fog that hovers invisibly in our homes, materializing into furniture or a bathrobe when we say so (Rogers and Kaplan, 1997/98).

Similarly, a speech³ given in January 2000 at California Institute of Technology (CALTECH) by President Clinton and the words⁴ of Senator Barbara A. Mikulski at the Wernher von Braun Lecture at National Aeronautics and Space Administration (NASA) Headquarters in June 2000 not only echoed the “endless frontier” metaphor, they also bore a striking resemblance to the Star Trek prologue – “going where no man has gone before.” From such rhetorical claims, we get the distinct impression that nanotechnology is certain to happen. We also get the image that a utopian world of infinite possibilities capable of producing nothing but favorable results for all humanity. And who wouldn’t

accept utopia if dished out on a nano-plated platter? In this way, the “endless frontier” rhetoric keeps the buzz alive and legitimizes nanotechnology as worthy of pursuit.

Competitiveness Crisis

While the U.S. had the luxury of developing microtechnology without serious competition until the early 1980s, it does not enjoy the same uncluttered environment in the development of nanotechnology. Born out of a crisis mode in which the area of nanotechnology is viewed by enthusiasts as fiercely competitive (Roco, Williams and Alivisatos 1999: 201), the urgency for establishing an effective national effort is driven by the realization that “at least 30 countries have initiated or are beginning national activities” (Thayer 2002: 18). The competitiveness crisis rhetoric in nanotechnology fulfills the role as an important persuasion tool. This is epitomized in the following claims:

Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science:

New tools will greatly enhance creativity, industrial design, and personal productivity. Failure to invest in the necessary multidisciplinary research would delay or even prevent these benefits to the economy, to national security, and to individual well-being. (National Science Foundation/U.S. Department of Commerce, 2002, p. 85)

Nanotechnology – Shaping the World Atom by Atom

The quest to master the nanoscale is becoming a global competition...Companies and countries are experimenting with new organizational, industrial and budgetary models they hope will give them the competitive edge toward these ends...whosoever becomes most knowledgeable and skilled on these nanoscopic scales probably will find themselves well positioned in the ever more technologically-based and globalized economy of the 21st century (Amato 1999: 2).

The Washington Monthly

The United States needs to push the science forward...We need to make sure that, as much as possible, the main research bases for this technology develop either on our own soil or with close allies...The most obvious danger would come if the United States falls behind the rest of the world and finds itself unable to control the technology. (Thompson 2000)

Social Utility

Historically, government policy has been built on a tradition of encouraging and actively sponsoring innovative science and technology research (Branscomb and Florida 1997: 13). However, economic deficits and spending restraints can hamper new programs and initiatives like nanotechnology. In the past, to maintain a steady flow of funding, rhetorical claims from the scientific community have utilized the ‘social utility’ principle: it builds compelling cases of what a particular science and/or technology can and cannot contribute to society. Here, the rhetoric calls upon traditional connections between scientific progress and social values for the public good. Below are some examples of the ‘social utility’ theme⁵ used to legitimize nanotechnology.

Suddenly things are turning up nanotech:

Boosters claim that nanotech-derived products may some day cure disease, slow the aging process and eliminate pollution (CNN.com 2003).

Becoming Immortal: Nanotechnology, You and the Demise of Death:

“nanotechnology will make possible immortality” (DuCharme 1995: 96).

Newsweek

One day in the next century, thanks to the burgeoning field of nanotechnology, you could walk out of the doctor's office with a prescription for cancer detectors so tiny you can't see them. The idea is that if we can build new drugs and devices molecule by molecule, the way the tissues and organs in our own bodies are formed, we can make them much more targeted and effective. One of the hottest areas of nanoresearch is better drug delivery. Going small could also mean killing off cancer cells early, before they grow into life-threatening tumors (Kalb 1999/2000).

Thus far, I have dealt with rhetorical claims in nanotechnology thematically, holding each theme in isolation to the other. However, it should be noted that in reality, within any rhetoric we can find the commingling of several, rather than single, ideological principles. For example, an analysis of Vannevar Bush's⁶ “endless frontier”

metaphor for science and technology shows that it was linked to two themes:

“competitiveness crisis” and the “inevitability of progress.”

Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn... Today, it is truer than ever that basic research is the pacemaker of technological progress... A nation which depends upon others for its new basic scientific knowledge will be slow in its industrial progress and weak in its competitive position in world trade, regardless of its mechanical skill (Bush 1998: viii).

Such links are also observed in nanotechnology. Rhetorical claims made by Nobel laureate Richard Smalley when he says that “nanotechnology is the builder’s final frontier...it holds the answer, to the extent there are answers, to most of our most pressing material needs in energy, health, communication, transportation, food, water, et cetera” (Thayer 2002: 17). Here, the social utility principle is enmeshed with the “endless frontier” metaphor as tools of obtaining credibility for nanotechnology claims. In sum, the rhetorical themes espoused in nanotechnology claims help serve as legitimizing devices for allocating resources for research and for enlisting supporters to nanotechnology.

Markets

Currently, there are three major competitive regions – Japan, Europe and the US – vying for dominance in the nanotechnology market primarily because anticipated advances in this field hold the promise of “big business.” The National Science Foundation (2001: 3-4) projects that over the next 10 to 15 years, global market turnovers of more than \$1 trillion annually are expected in the areas of manufacturing, electronics, health care, pharmaceuticals, chemical plants, transportation, and environmental sustainability. A study conducted by Consulting Resources estimated the market for nanomaterials at close to \$200 million and expanding to \$4 billion by 2007. This market

involves practical applications such as sensors, motors, gears and other micromachines. Basic sensing devices are said to be part of a \$2 billion industry that some experts predict will be worth more than \$100 billion by 2010 (Rogers and Kaplan 1997/98).

Another study conducted by Business Communications Company anticipated a global market growth for nanoparticles in biomedical, cosmetic, and pharmaceutical applications at 8.3% per year to \$144.8 million in 2005 with the fastest-growing market in sunscreen products. Other major markets for nanoparticles include electronic and magnetic applications, such as chemical mechanical polishing slurries, magnetic tape coatings, and optical fibers. In these electronic and magnetic markets, sales are expected to generate a combined total of more than \$330 million per year and are likely to grow 14.9% per year through 2005. (Schmitt 2001). Also, the market for nanotechnology based products including chemicals, materials, healthcare and electronics is expected to grow an average of 48% annually over the next decade and reach sales of \$20 billion by 2013. This reflects a 50-fold growth over the next 10 years from an estimated sales level of some \$385 million this year (The Advanced Semiconductor Magazine 2003).

Traditionally, free markets and belief in them has had a major effect on the control of technological innovation in the United States, displacing social objectives and accepting only those that seem compatible with either increased military strength or commercial profits (Hart 1998: 9). Similarly, the economic and national security imperatives of the competitive marketplace are, as Ray Kurzweil confirmed in his Congressional Testimony at the 2003 Committee on Science Hearings, driving nanotechnology forward and fueling the need for greater scientific legitimacy.

Funding

The nanotechnology race for greater market share has resulted in vigorous research efforts by the three competitors (Spotts 1999). Such efforts require considerable economic investment in nanotechnology claims. At a three day conference in Seattle, Washington in 1989 called NANOCON, Quel (1989: 5), initiator of the conference, highlighted the role of such investment to the growth of nanotechnology. “[The] history of human progress is the history of evolving ideas and institutions...while society cannot be reduced to economics, there is an undeniable under-pinning of economics to social action.” Thus, nanotechnology has become one of the most sought after recipient of corporate and government funding.

This is seen in the fact that “the nebulous field of nanotechnology, freighted with as much hype as legitimate promise, has lured the likes of IBM, Motorola and Dow Chemical” (Fahley 2001: 1). Thanks to a \$15-million infusion of venture capital from chemical industry investors, Carbon Nanotechnologies (CNI) – a technology startup – is hoping for mass-production of single-walled nanotubes. With these funds, CNI will build a pilot plant that will set the stage for raising \$50 to \$100 million more in venture capital to begin working toward commercial-scale production by early 2005 (Fairley 2001). According to DuCharme (1995), over 50 investment firms in the U.S. announced their intention to focus dollars in nanotechnology.

Governments have also joined the “bandwagon” by investing equally large sums of money to advance nanotechnology. For example, Japan’s Ministry of Economy, International Trade and Industry has approved funding for two five-year nanotechnology projects. The first (5 billion yens to the New Energy and Industrial Technology

Development Organization, Tokyo) will focus on nanoscale chemical processing technology. The second (3.75 billion yens to be assigned to a group of universities) will study nanomaterials and composites (Franz and Sissell 2001). Other Japanese agencies work in nanotechnology research and development with approximately another \$300 million in funding (DuCharme 1995: 46). Although, the Japanese recognize that the U.S. is ahead in the race, Crawford (1991: 1305) noted that they also realize that to compete, “government support is critical.”

In the United Kingdom (UK), the pattern of government spending is equally grand. Recently, the Science and Innovation Minister, Lord Salisbury announced 90 million pounds in nanotechnology investment to be allocated as follows: 50 million for an Applied Research Programme to support collaborative research and development (R&D) projects between industry and the science base; and 40 million for a Micro Nano Technology (MNT) Network to drive market development and exploitation around the UK, helping industry access nanotechnology research and resources. According to The Semiconductor Magazine (2003), existing and anticipated nanotechnology projects supported by the UK development agencies are expected to exceed 200 million over the next few years.

In the U.S., “decisions on priorities among different areas of research are made mainly in the context of the federal budget process” (Teich and Wiaz 1986: 36).

Nanotechnology is a top priority in the U.S. as reflected in the words of Jack Lev, Director of the Office of Management and Budget who notes that nanotechnology “will open doors to science and health research that are closed... We’re going to stick to our guns, and we’re going to keep insisting on better funding... because we believe it’s very

important” (Roco, Williams and Alivisatos 1999: 271-272). To remain competitive with other nations, the U.S. government must make substantial investments (Branscomb et al. 1997: 2), and therefore, has focused much of its efforts on funding nanotechnology research through the federal budget process. On February 7, 2000, President Clinton officially proposed a National Nanotechnology Initiative (NNI), recommending an 83% budget increase in federal funding for R&D on nanotechnology in a single year, from \$270 million in fiscal year (FY) 2000 to \$495 million in FY 2001. This represented nearly a doubling of federally supported research in this area (Schulz 2000).

This initiative received strong presidential and congressional support during the Clinton Administration (Malkinson 2002) and was expected to continue within the Bush Administration as well. In a 2001 *UCLA Today* article, Cynthia Lee reported that “a high-ranking official from the U.S. Department of Commerce told more than 100 Southern California business and academic leaders and state and federal policymakers...that President Bush wants to increase federal investment in nanoscience research by 23% next year to \$519 million.”

Through the NNI, the goal of the Bush Administration and federal government was to ensure consistent and coordinated investment in this emerging technology. For the FY 2002, funding request for nanoscale science, engineering and technology R&D increased even further. The initial request to Congress was \$518.9 million. However, the total nanotechnology budget enacted by Congress was approximately \$604 million, 43% over \$422 million for FY 2001. Table 2.1 below shows funding patterns of government agencies in the NNI. This is then followed by a discussion of selected agencies. See Appendix F for list of acronyms.

Table 2.1: Nanotechnology Investment for Federal Agencies (FY 2000-FY 2002) in Million of Dollars

Department/Agency	FY 2000 NNI Budget	FY 2001 Enacted	FY 2002 Request/Enacted
<i>NSF</i>	97	150	174/ 199
<i>DOD</i>	70	110	133/180
<i>DOE</i>	58	93	97/91.1
<i>NIH</i>	32	39	45/40.8
<i>NASA</i>	5	20	46/46
<i>NIST</i>	8	10	17.5/37.6
<i>EPA</i>	-	-	5/5
<i>DOT</i>	-	-	-/2
<i>USDA</i>	-	-	-/1.5
<i>DOJ</i>	-	-	1.4/1.4
Total	270	422	518.9/604.4 (+ 43%)

Source: National Nanotechnology Initiative. "National Nanotechnology Investment in the FY 2002 Budget Request by the President."

Department of Defense (DOD)

As one of the founding agencies of NNI, nanotechnology has long been a part of the DOD program. In FY 2000, Congress took \$10 million of the \$20 million targeted for university research and instead gave it to the Defense Advanced Research Projects Agency (DARPA) for nanotechnology research. Robert Trew, head of the DOD's nanotechnology effort noted that another \$10 million was provided for DOD laboratory work in nanotechnology (Schulz 2000). The FY 2002 request, initially \$133 million, was augmented to \$180 million, \$70 million over the enacted FY 2001 budget. The importance of funding lies in DOD's ability to maintain a vital edge on the battlefield: nanotechnology is perceived as critical to future military readiness (Roco 2002a).

Department of Energy (DOE)

For DOE, a \$58 million NNI budget request went before Congress in FY 2000. For FY 2002, the \$91.1 million budget was an increase of \$3 million over FY 2001 for the Basic Engineering Sciences (BES) project related to the establishment of user centers for nanoscience research, and of \$6.1 million for the Office of Defense Programs (Roco 2002a). The director of the agency, Patricia M. Dehmer noted that BES supports two

types of activities under NNI: awards to individual investigators or small groups of investigators in DOE laboratories and/or academia and awards for the establishment of Nanoscale Science Research Centers (NSRCs), which is one of the more visible NNI projects (Schulz 2000). Like DOD, federal funding made DOE a key player. Its commitment to the establishment of NSRCs is also important to NNI as they aim to build coalitions by bringing together the research and facility missions of national laboratories with the educational role of universities and problem-defining capabilities and needs of the industry.

National Institutes of Health (NIH)

As part of the NNI initiative, NIH's main priority is to "bridge basic discoveries to tomorrow's new treatments, including nanotechnology advances for development of sensors for disease signatures and diagnosis of diseases" (Roco 2002a). The FY 2002 request, initially at \$45 million, was adjusted to approximately \$40.8 million, still an increase of \$1.8 million above the approved level in FY 2001. The NIH's increased investment in nanotechnology research is planned to develop novel instruments to collect DNA sequence variation and gene expression data from individual patients.

National Aeronautics and Space Administration (NASA)

According to Dagani (2000: 36), NASA is "an agency driven by dreams...to make [its] grand visions come true, NASA knows it will have to exploit new technologies that involve controlling matter on the nanometer scale...Put it this way: NASA is hitching its star to nanotechnology." It already embraced nanotechnology through several initiatives: a five-day sponsored conference entitled "NanoSpace 2000 – Advancing the Human Frontier" and collaborative work with other organizations whose

interests overlap its own like its close ties with chemistry Noble Laureate Richard Smalley, who directs the Center for Nanoscale Science and Technology at Rice University. The funding that the NNI provides is of substantial importance to advancing NASA's priorities. The FY 2002 request was \$46 million, \$26 million over FY 2001. NASA's major focus is to advance and exploit the zone of convergence between nanotechnology, biotechnology and information technology for space exploration. In addition, up to \$1 million per year was spent to on understanding the societal and ethical implications of nanotechnology, with a focus in monitoring human health.

National Institute of Standards and Technology (NIST)

Clinton's 2000 NNI budget proposed an increase of 12% in the Technology Administration's total funding, to \$713 million, with NIST's programs receiving modest increases to support nanotechnology. In 2002, NIST funding for nanotechnology-related projects totaled almost \$40 million and there seems to be no signs of this slowing down. For the FY 2004, President Bush requested a funding increase of \$5.2 million to further NIST's nanotechnology efforts. The NIST plays an important role in creating and maintaining the scientific legitimacy of nanotechnology. It is a non-regulatory federal agency within the U.S. Commerce Department's Technology Administration and is the nation's premier measurement laboratory. Its mission is to develop and promote measurement, standards, and technology to enhance productivity, facilitate trade, and improve the quality of life.

The stated appeal of NIST is that technology, measurements and standards help U.S. industry invent and manufacture superior products reliably, ensure a fair marketplace for consumers and businesses and promote acceptance of U.S. products in

foreign markets (<http://nanotech-now.com/government.htm>). However, this appeal is not a purely instrumental one, rather it has a social and moral component, shrouded in the cloak of impersonality, discipline and rules that the world of science has fashioned. When science measures and numbers are validated, it provides legitimacy for action; and as Ezrahi (1990) pointed out, “through scientific constructions of regularities” or standards, it acts as a latent function in upholding authority and accountability structures and in making people and actions appear trustworthy. NIST is an important element in enabling trust – “faith in impersonal technological and regulatory mechanisms” – that can discipline people, as well as standardize instruments and processes. Its measurement and standards achieve a “kind of objectivity” that aspires to “independence from local customs and local knowledge” (Porter 1995: 22). Thus, NIST serves as a powerful tool to defend (or attack) choices to fund a particular technology or scientific endeavor. The apparent certainty of “hard numbers” provides a powerful defense for legitimacy in nanotechnology.

In sum, nanotechnology has a very high wow index. Vicki Colvin, Executive Director of the Center of Biological and Environmental Nanotechnology testifies at the 2003 House Committee on Science Hearings that “all this “good news” has created a growing perception among business and government leaders that nanotechnology is a powerful platform for 21st century technologies.” As we have seen, this has given the field a strong start with extraordinary levels of funding. Ultimately, how nanotechnology becomes legitimized will continue to rest in part on who funds it and how its research monies are allocated.

Policy

According to Gottweis (1998: 4), policy is “situated at the intersection between forces and institutions deemed “political” and those apparatuses that shape and manage individual conduct in relation to norms and objectives but are deemed “non-political,” such as science or education.” Press (1981: 249) also showed that the “non-political” – scientific and technological considerations – have long been integral parts of U.S. policy deliberations on defense and foreign policy issues like strategic weapons modernization, arms control, technology transfer, the growing bilateral relationship with China, and North-South relations. The government has been responsible for the origin, development, and progress of many scientific efforts, for example, the atomic bomb, the computer and the internet. “That politics and government act as substantial influences on the undertakings of science and technology appears obvious” (Shapin 1995: 356-357) today. But this was not always the case.

Prior to World War II, the responsibility of setting standards for the science-policy relationship was the role of the President. In this era, scientific activities were not seen as matters of central importance to great public issues and were originally nurtured as a private enterprise. In fact, scientists were skeptical of federal support, and government maintained a hands-off approach to its involvement in science, except to protect freedom of inquiry and to provide patents for new inventors. However, this all changed with the Soviet Sputnik launches. Driven by what was perceived as a major crisis – the race to compete with the rest of the world and their technological developments, Smith (1990) noted that it was during this time that the role of the

presidential scientific advisors was significantly broadened, and the president became more involved in the institutional issues of science policy.

World War II became the defining moment in American federal research policy history, generating new ideas and assumptions about science and technology, and bringing together science and government. To keep pace with the growing importance of science and technology, the National Academy of Sciences (founded in 1863) was expanded to include the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970. Enlisting committees of the nation's top scientists, engineers and other experts, these non-profit organizations functioned to work outside the government framework to ensure independent advice on science, technology, and medicine matters (<http://www.nationalacademies.org/about/about.html>).

No longer was scientific knowledge viewed as knowledge for its own sake but it was now for society. This became the major thrust for scientific research, with government now charged as the agent protecting society. This meant that science and technology development became enmeshed in the political process, no longer "exempt from the rough and tumble of politics" Smith (1990: 8). This new link marked the beginning of the era of modern U.S. research policy (Teich and Wiaz 1986) and is described by Don Price (cited in Hiskes and Hiskes 1986) as possibly one of the most significant discoveries.

This new science/government relationship has been widely attributed to the moral nature of the war experience. But, as Hiskes and Hiskes (1986) point out, it was also due to the inclusion of the scientific community into the war effort to promote the development of nuclear power, radar and new weapons. Policy and support for science

based on the production of technological feats became the driving force of this era, and this continued into the post-war years. According to Dickson (1984), this was then followed by a decade in which the main thrust was to make science directly relevant to social needs – tackling health, unemployment, environmental problems, etc. The tendency here was to treat science and technology as band-aids for solving every pressing problem or crisis. For instance, to solve the unemployment problem, why not create new industries based on new technologies.

In the 30 to 40 years following World War II, this approach in American science and technology policy can best be described as a “traditional” pattern; its roots situated in the Vannevar Bush’s 1945 report, *Science – the Endless Frontier* to President Truman:

It has been basic United States policy that Government should foster the opening of new frontiers. It opened the seas to clipper ships and furnished land for pioneers. Although these frontiers have more or less disappeared, the frontier of science remains. It is in keeping with the American tradition – one which has made the United States great – that new frontiers shall be made accessible for development for all American citizens (Bush 1998: 11).

Bush’s “endless frontier” policy model called for broad government commitment to R&D, and placed special emphasis on fostering basic research in universities and on developing scientific manpower. During the “endless frontier” era, Heaton et al. (2001: 1-2) noted that large government programs – defense, space, atomic energy and health – dedicated to fulfilling particular government missions, dominated this era.

Then came a moment of change around the 1980’s, defined by a competitiveness crisis model (Heaton et. al 2001). This model was exemplified in a wave of national initiatives that began in 1988, in which a host of federal and state programs focused on technology commercialization. Policy for science and technology emphasized potential contributions to the competitive strength of American industry and to military

technology. Describing this new policy thrust, Dickson (1984:17) highlights that suggestions from the private sector became significant elements directing government research priorities; the ties between universities and private corporations were being renewed; and states were acting as “marriage brokers to such alliances, keen to promote high technology solutions to local development problems and to accept whatever conditions the private sector lays down for its cooperation.” What this new agenda implied was the development of science and technology policy almost exclusively based on the needs of the military and the marketplace. Two policy principles – financial support for basic research and commercial “spin-off” from mission-oriented R&D – became the guiding principles of national policy initiatives.

In policy discussions about nanotechnology, these same principles are present and sustaining its growth. For example, in March 1998, the President’s Science Advisor Dr. John H. Gibbons identified nanotechnology as one of the six technologies that will determine economic development in the next century. Then, in an April 1998 Congressional Hearing, Neal Lane, Assistant to the President Clinton for Science and Technology and former Director of the NSF proclaimed: “If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering” (Amato 1999: 1).

These government officials are not alone in such views. Many former and current policy makers call for sound government policy on nanotechnology based on these principles. At the U.S. Senate Science and Technology Caucus Roundtable Discussion on April 5, 2000, Senator Evan Bayh emphasized the importance of nanotechnology research to the “future rates of innovation in the country...Innovation is the key to our

comparative advantage in the global economy...It is vitally important that we increase our investment in the physical sciences, including nanotechnology, if we are to see increases in productivity and incomes in the years ahead” (Roco, Williams and Alivisatos 1999: 271).

While there are those that claim industrial entities should be the regulators of science and technology decisions and funding, most policymakers feel that the federal government should play an important, if not necessary, role in facilitating new scientific knowledge and developing new technology. In nanotechnology, this is evidenced by the growing number of policy documents, projects and initiatives emerging from the government agencies. NSF started its own initiative, “Synthesis and Processing of Nanoparticles” in 1991 and its own National Nanofabrication User Network in 1994. The Department of Defense identified nanotechnology as a strategic research objective in 1997, and the National Institutes of Health identified nanobiotechnology as a topic of interest in its 1999 Bioengineering Consortium (BECON) program (Roco, Williams and Alivisatos 1999: xvii).

Moreover, Phillip J. Bond, undersecretary for technology at the Commerce Department, solidifies the significance of policy in this area when he claims that “for most of U.S. history, the government has had a good track record of supporting innovation...By any measure, the U.S. is ahead [in nanotechnology research and development]...and it will remain so with enlightened public policy. We need wise public policy to enable the technology, and the National Nanotechnology Initiative is a manifestation of that” (Schulz 2003: 22).

National Nanotechnology Initiative (NNI)

The NNI is a U.S. multi-agency science and technology proposal aimed toward developing and perfecting the ability to create new structures by working at the atomic level (Lewis 2001). The idea for this initiative first took root in 1998 when the White House National Science and Technology Council (NSTC) created the Interagency Working Group on Nanoscience, Engineering and Technology (IWGN). Later, in March 1999, it was openly proposed in a presentation by Michal Roco at the White House Office of Science and Technology Policy (OSTP). However, it wasn't until August 1999, that it got its official start upon the release of the IWGN's first report, "Nanostructure Science and Technology." In the report, workshop participants and contributors concluded that "the national nanotechnology initiative... would leverage the existing strong foundation of nanoscience in the United States... It will seize nascent opportunities to advance this field, stimulating domestic job growth and strengthening U.S. competitiveness in international markets" (Roco, Williams and Alivisatos 1999: xviii).

A few months later on January 21, 2000, in a speech at CALTECH, President Clinton began to lay out plans for NNI when he announced that his "budget support[ed] a major new Nanotechnology Initiative, worth \$500 million" (Clinton 2000) because he felt that "science and technology have become the engine of our economic growth." Then in his 2000 State of the Union address on January 27, he asked Americans to imagine "materials with ten times the strength of steel and only a small fraction of the weight, shrinking all of the information housed in the Library of Congress into a device the size of a sugar cube, detecting cancerous tumors when they are only a few cells in size" (Thompson 2000). There, he set the stage for full endorsement of the NNI. In 2001, NNI

was officially launched after having been approved by Congress in November 2000.

Under NNI, the NSF, along with partners such as NASA, NIH and DOD would provide money to researchers to further knowledge about nanoscience and technology (Belsie 2000).

By August 2002, four more participants were added to the subcommittee: the Environmental Protection Agency (EPA), the Department of Agriculture (USDA), the Justice Department (DOJ) and the State Department. The NSTC Subcommittee on Nanoscale Science, Engineering and Technology (NSET) was put in charge of coordinating the Federal government's multi-agency nanoscale R&D programs, which included the following activities: fundamental research, grand challenges, centers and networks of excellence, research infrastructure, ethical, legal and social implications and workforce programs. According to Chang (2002) and Roco (2002b), this initiative and similar ones worldwide (Australia, Canada, Europe, and Japan) have led to calls within the scientific community for concerted efforts to educate future scientists and the general public regarding ongoing developments in nanoscience and nanotechnology.

Coalition Building

Star and Griesemer (1989) claim that scientific work is conducted by extremely diverse groups: heterogeneity is a reality and science requires cooperation. Furthermore, Bijker and Pinch (1987) in their technological frame argument suggest that we are likely to find many different epistemic cultures of technology. Stabilization of any technology depends on various levels of aggregation: national differences, technology branch differences, differences between technologies or artifacts, differences between and within companies.

Such variation is perhaps most evident in nanotechnology where Roco, Williams and Alivisatos (1999: xxix) point out that “the requirements for and from nanotechnology transcend anything that can be supplied by traditional academic disciplines, national laboratories or even entire industries.” This is primarily because of nanotechnology’s multi-interdisciplinary nature, which requires more collaborative endeavors than previously observed in other areas of science and technology like microtechnology and biotechnology. Among the many challenges – technical, funding, and science and technology workforce (Lane 2001) – to nanotechnology’s growth, strong coalition-building through collaborations and partnerships at the academic level [across disciplines], at the business level [across organizations], at the policy level [across government agencies] is critical.

At Academic Level

According to scientists working in this field (DuCharme 1995, Drexler 2002 and Werthamer et al. 1992), nanotechnology by nature is multi-interdisciplinary. It is not a completely new discipline unrelated to anything else as it is made up of elements of already existing science and technology. As indicated by Mehta (2002: 269), it represents “a theoretical and procedural convergence of quantum physics, molecular biology/biochemistry, computer science, chemistry, and engineering.” Furthermore, nanoscience/technology falls within a new realm of scientific and technological couplings as “techno-science” (Latour 1987). This means that the traditional view of science and technology as separate practices, working in isolation as separate communities of specialized professionals without interference, is inappropriate.

Rather, as Nordmann (2003: 1) puts it, “nanoscale research is driven by a sense of place, it is defined by the site at which chemists, computer engineers, physicists, materials scientists, and now even philosophers converge. The notion of technoscience abandons the distinction between basic and applied science, between science and technology altogether.” This has meant that not only the work of scientists has broadened from single, isolated perspectives to multiple judgments and interests, but that gaining legitimacy requires supporters to increasingly draw upon a wide circle of experts; experts with their own interest, ethics, values and judgments that ultimately influence the nanotechnology field.

Getting to nanotechnology requires the work of many experts in differing fields: chemists who are learning how to make molecular machines; computer scientists who are building design tools; and scanning tunneling microscopy (STM) and atomic force microscopy (AFM) experts who can provide tools for molecular positioning. In order “to make progress...these experts must do more than just work, they must work together” (Drexler 2002: 13). This coalition building effort is aptly expressed in the following:

This field will require close collaboration between physical and biological scientists, and an ability to communicate the mathematical and biological concepts between specialists in order to bridge these disciplines...While nanotechnology has a great deal of promise for biotechnology applications, there are major challenges to be overcome. The greatest may be the barrier between physics and engineering, on the one hand, and biology, on the other. To grasp current concepts in physics and engineering requires highly sophisticated mathematical skills, far beyond the college algebra and calculus with which biologists are equipped to deal. On the other hand, nanotechnology can only be applied to biological issues when the dimensions of the problem are understood, requiring extensive training in biomedical sciences. This gulf can be bridged by finding ways to bring the physics and engineering communities together with biologists and clinicians in a synergistic and productive fashion (Morrow 2002: 26-29).

This can be a daunting task when one considers as Bauer (1997: 23) does that while “there is good reason to think of the academic disciplines as cultures, whose members

have not only a common intellectual task but also many values and many characteristics of behavior in common...one consequence [is] that disparate answers may be offered by various disciplines to any given question...each discipline looks in its own manner for the answer, and each seeks its own sort of answer.” This is further complicated by nanotechnology’s multi-interdisciplinary nature as Drexler (2002: 13) asserts that “countries that draw hard lines between their academic disciplines, as the United States does, will find that their researchers have difficulty communicating and cooperating.”

Nevertheless, as nanotechnology grows, it is breaking down borders between different fields – from engineering to biology – creating the type of coalitions needed to expand the field. For instance, there are a large number of nanotechnologists and researchers working together in U.S. institutions from the CALTECH to the NASA Ames Research Center (Ebisch 2003). At Rice University, as at a growing trickle of other universities, administrators keep a close eye on the changing needs of the marketplace as they prepare students for careers in science. Over the last fifteen (15) years, for example, Rice has created a Quantum Institute, which combines faculty from the physics, chemistry, space physics, astronomy, materials science and chemical, mechanical, electrical and computer engineering departments (Crenson 1994). The creation of a new nanocenter at Georgia Tech promises to bring more collaboration and partnerships with the private sector that would lead to start-up firms.

At Business Level

The many arms of nanotechnology research have not cut a single path forward. To progress, Thompson (2000) recommends that there needs to be constant information sharing among companies and businesses. The process of legitimizing nanotechnology

therefore depends upon strong coalition-building at the business or private sector level. By working together, industries hope to achieve at a faster pace the technological applications promised by nanotechnology. Examples of such partnerships include CNI, a company that recently signed an engineering agreement with Kellogg Brown and Root (KBR) to commercialize production of single-wall carbon nanotubes (Wood and Franz 2001), and Mitsubishi Corporation that established a joint venture called Fullerene International with Materials and Electrochemical Research Corporation and Research Corporation Technologies (Fairley 2001).

At Policy Level

In the U.S., it is not enough for a President to propose a new initiative. “In practice, the President’s power to control the activities of the agencies of the executive branch, while substantial, is less than absolute. It is limited by several factors, including the influence of Congress, the influence of outside interest groups and the sheer size of government” (Teich and Wiaz 1986: 37). For any new initiative to succeed, advocates must build a coalition and persuade Congress to provide the funding. In the case of nanotechnology, Heaton et al. (2001: 12) highlight that when the NNI was proposed, it did not come from a strong industry coalition or even from a coalition of scientific and technical societies. Rather, it came out of the Executive branch.

This does not imply that coalition-building played no part in the success of the NNI. Heath et al. (2001) identify four specific activities that were important to the development and implementation of NNI. First, mid-level agency experts became interested in nanotechnology and began talking to colleagues in other agencies. They then talked to White House staff, supplying their ideas about nanotechnology policy.

Second, staff-level policy entrepreneurs at the White House were receptive to ideas for the initiative. The interest that White House staff – themselves policy entrepreneurs – showed in nanotechnology did not result from a desire to please key political constituencies or to distribute benefits to particular industries. Rather, the potential benefits for U.S. economic competitiveness, as well as benefits for other important areas such as national security and health, were driving forces behind its reception: “this once obscure science is about to be a trillion-dollar piece of the global economy, and the transition in our educational institutions, our government and our businesses needs to begin today” (Schulz 2003: 21)

Third, Presidential endorsement was critical to persuading Congress to provide funding for the NNI. In September 1998, the White House’s science and technology coordinating body, the National Science and Technology Council (NSTC), created a formal interagency workshop to study nanotechnology (IWGN). The creation of this working group provided a formal mechanism for studying the topic, increasing familiarity about the technology and enrolling spokespersons already involved in nanotechnology. Finally, policy entrepreneurs launched an interagency effort to bring people from different agencies to work together to forge multi-agency R&D initiatives, with the vision of a “grand coalition” with specific objectives for nanotechnology supporters in academe, private industry, government laboratories, government funding agencies, and professional science and engineering societies.

Thus, a vital tool in establishing and maintaining scientific credibility in nanotechnology was and continues to be coalition-building through partnerships and collaborations at the academic, business and policy levels. The case in this study, that is,

the collaborative workshops between nanoscientists at Virginia Tech and high school teachers, is a fitting example of this legitimizing technique. It is also important to add here that for successful coalition building to occur in nanotechnology, we not only need different groups coming together. It depends on the interests, motivations and perspectives of those involved in this work. Nanoscientist Jay Ponder sums it up quite succinctly in this way:

It's all a matter of what's perceived to be important by the different groups that have to come together to make this work: the chemists doing their bit and the computational people doing their bit. People have to come together and see the big picture. There are people who try to bridge the gaps, but they are rare compared to the people who just work on their own specialty (Drexler 2002: 14).

That legitimizing nanotechnology is ideally contingent upon diverse actors with their own perspectives working together is evident. What is also apparent is that nanotechnology's multi-interdisciplinary nature opens it to a host of social, political and economic contingencies that may either contribute to or impede its ability to grow.

Situating Nanotechnology in Science and Technology Studies

Areas of research, such as philosophy, sociology of knowledge, sociology of science, and science studies, also referred to as Science and Technology Studies (STS) and Social Studies of Scientific Knowledge (SSK) investigate the processes, practices, and artifacts of knowledge production. In particular, science studies or STS is a term for the collection of empirical studies and analytical perspectives that examine how participants in science and technology agree about what counts as fact or discovery, what inferences are made from facts, what is regarded as rational and objective, and how the credibility of claims is assessed (Latour 1987, Longino 1990, Haraway 1991). This case study relied upon the STS approach because of its relevant concern with scientific

knowing, and with the practices and principles by which scientists decide, collectively and individually, what they know.

Although this body of work is far from monolithic in terms of approach or conclusions, it shares the view that “[if] we can know to what extent the economic, political, religious [and/or social] factors influence science and scientific activity, we should be able to determine the extent to which the development of science is a result of its own imminent growth” Gittler (1940: 356). In STS, there are essentially three ways of viewing science: as a set of procedures for finding things out; as a social enterprise, culture, tradition or set of social arrangements for developing, certifying and communicating knowledge; and as a body of certified knowledge (Zuckerman 1988).

This case study was concerned with the latter version of science, which finds expression in the words of Claxton (1997: 74):

Science ... is both a content and process. As content, the most appropriate analogies for science itself are maps and languages, whose value inheres only their ability to facilitate the human purposes, preeminently, of articulate explanation and technical control... As process, science is loosely characterized by an interplay of observation and experimentation, deduction and induction, governed by criteria of coherence, elegance and parsimony, which result in interesting speculation, productive explanation and/or successful prediction. This core cognitive cocktail, the proportions of which depend on the nature and maturity of the science in question, is mixed, consumed and judged within a context of personal, social, political and financial pressures which influence the process in a variety of ways.

Thus, science, if viewed as “a body of “knowledge” should more accurately been seen as “a set of languages or “maps” than an incontrovertible edifice of truth... just as there is no one “best” map of London, say, no ‘true’ representation, so scientific theories and languages are also, necessarily, multiple and complementary.” Moreover, these languages of science are “saturated with metaphors and symbols borrowed and adapted from the vernacular” and the scientific maps, like all maps, are “works of human

invention” that are borrowed from the “known to chart the unknown.” In this study, science was viewed as “a loose-knit family of ways of knowing” (Claxton 1997: 71-72).

The Sociology of Scientific Knowledge (SSK)

Over the past two decades, interdisciplinary studies of the sciences have been dramatically transformed by SSK (Rehg 2000). Dating from the insights of Kuhn (1962) and earlier developments in the philosophy of science (Feyerabend, 1975, Lakatos 1970), an extensive body of empirical and theoretical work in STS has emerged that examine the social construction of scientific knowledge and the communities that produce such knowledge (Barnes 1974; Bloor 1976; Knorr-Cetina 1981; Latour 1987; Latour and Woolgar 1986; Lynch 1985; Pinch 1986; Traweek 1988). Also, sociologists have shown links between SSK and the sociology of work, occupations, and culture (Clarke 1990; Clarke and Montini 1993; Star 1989b; Star and Griesemer 1989; Mukerji 1989; Fujimura 1987, 1988). Several studies have incorporated the SSK findings into programs of science communication and liberal education (Collins and Pinch 1993; Chambers and Turnball 1989) and science and technology policy (Jasanoff 1990, 1992; Wynne 1992; Fuller 1993; Epstein 1993). SSK has also received much attention from historians and philosophers (Shapin 1982; Shapin and Schaffer 1985; Rudwick 1985; Golinski 1990; Dear 1995; Rouse 1987; Hacking 1992, 1999).

According to Shapin (1995: 306), these works typically address “the embodied nature of scientific know-how and the embodied vectors by which it travels, whether the embodiment is reposed in skilled people, in scientific instruments, or in the transactions between people and knowledge-making devices.” An example of such work can be found in Collins’ classic study (Collins and Harrison 1975) of the transfer of laser-building

skills as embodied tacit knowledge. Additional examples can be found in the ethnomethodological and symbolic interactionist studies of modern biology (Lynch 1985; Jordan and Lynch 1992; Clarke and Fujimura 1992; Cambrioso and Keating 1988), mathematics (Livingston 1986), in historical work on physics (Shapin and Schaffer 1985, Morus 1988), astronomy (Van Helden 1994), chemistry (Roberts 1991, Golinski 1994), genetics (Kohler 1994) and medicine (Lawrence 1985).

The historical development of SSK can be traced to two sociological frameworks: the sociology of knowledge and the sociology of science. Primarily a German product springing from the works of Max Weber, Max Scheler, Karl Mannheim and others, the first framework sought to show that “there are modes of thought which cannot be adequately understood as long as their social origins are obscured” (Gittler 1940: 350). Intellectual life and thought was conceived as operating within a social milieu, which pervade the thought so as to influence its very mode and form. The sociology of knowledge attempted to understand thought in relation to its place in the historical-social scene. According to Bloor (1976: 5), it focused on “the distribution of belief and the various factors which influence it,” and it attempted to address the following questions: “how is knowledge transmitted, how stable is it, what processes go into its creation and maintenance, how is it organized and categorized into different disciplines or spheres”? (Bloor 1976: 5)

Similarly, knowledge as socially constitutive gained momentum within the sociology of science: an interdisciplinary specialty in STS, with uneasy connections to history, philosophy of science, science policy and psychology of science. According to Gittler (1940: 351), by sociology of science, we mean “that aspect of sociology which is

concerned with the study of, and the extent to which, science influences and is influenced by the prevailing values, attitudes, mores, habits, institutions, and customs of society, or of a given segment of society, at a specific time and place.” It is an attempt to view science – its methods, thought-models, accomplishments, acceptance, and so on – in light of the social situation.

Preferring to use the term, “the institutional sociology of science,” Hess (1997: 52) confines this field to the body of work associated with Robert Merton, developed from the sociology of occupations. In this perspective, science was seen as another occupation, and sociologists in this tradition tended to view with suspicion the argument that a good sociology of science required an understanding of the content of science. Zuckerman (1988) however, extended the scope of the sociology of science to include a variety of connected matters: the effects of science on society; the structure of science; and the processes through which production of knowledge occurs. For her, the sociology of science can be categorized into four large divisions: the sociology of the scientist, the sociology of scientific institutions and organizations, the sociology of applied science, and essential to this case study, the sociology of scientific knowledge.

From the sociology of knowledge and the sociology of science, it was only a matter of time before sociologists linked the two. The common strand that united them was the view that “what is accepted as scientific knowledge is relative to the culture or mode of life in which it is embedded” (Halfpenny 1991: 213). This view made scientific knowledge amenable to sociological investigation. Departing from an emphasis on institutional or contextual aspects of science associated with Merton’s work, SSK focused instead on the content – theories, methods, design choices and other technical aspects – of

science. To describe this emphasis on “content,” Knorr-Cetina and Mulkay (1983) uses the term “methodological internalism,” that is, how the “internal” practices of the scientific enterprise constitute the focus of inquiry.

The work of Mulkay, Collins, Barnes and Bloor during the 1970s is usually flagged as the starting point of the contemporary period of SSK. Until the 1970s, sociologists generally believed that social factors played a minimal role in shaping scientific knowledge, and thus, chiefly examined the lives of scientists but did not analyze science itself. But in the mid-1970s, philosopher David Bloor, sociologist Barry Barnes, and historian Steven Shapin introduced the Strong Programme, which critiqued the notion that science is (or has been) practiced by following a set of rules, as suggested by the rationalist philosophy of science enunciated by Karl Popper. In doing so, they not only extended the purview of sociology to include the analysis of how scientific knowledge is produced, but also, highlighted the contextual nature of knowledge and explanation (Bloor 1976; Barnes 1974), revealing that scientific knowledge was and is in fact mediated by social and other factors.

One way of characterizing SSK is within the rubric “social constructivism,” which assumes that “artifacts and practices are underdetermined by the natural world and argues that they are best seen as the constructions of individuals or collectivities that belong to social groups... [it] works on the assumption that the social lies behind and directs the growth and stabilization of artifacts” (Law 1987: 111). It is the general label for any social studies approach that attempts to trace the ways in which social interests, values, history, actions, institutions, networks, and so on shape, influence, structure, cause, explain, inform, characterize or co-constitute the content of science. Studies of

this sort examine how social variables shape the pattern of choices about what research gets done, how it is done, how choices among theories are made in controversies, and the extent to which observations, laws, theories and other knowledge claims become accepted in wider scientific communities (Hess 1997).

However, it should be noted that SSK itself is not of one conceptual piece. According to Zuckerman (1988), there are essentially two streams of thought within SSK: those that emphasize the social influences on structure and development of scientific knowledge and those that study the social construction of knowledge itself. The former, referred to as the structuralist position, sees science pace, direction, mode of control and structure as amenable to social influences but stop short of attributing to social conditions the determination of logical and conceptual structure of scientific arguments.

The latter is the constructionist position which engages in a variety of inquiries: those employing relativist and constructivist perspectives, those treating the impact of social and professional interests, and discourse or text analysis. While researchers adhering to this position differ in their methods, their theoretical and epistemological orientations, and problems they address, they challenge the objectivist, rationalist view of science that holds evidence and logic to be prime determinants of scientific validity and theory choice. They address in what sense and to what degree we can speak coherently of knowledge as being rooted in social life.

This changing conception of scientific knowledge has been accompanied by a revised view of rationality that no longer regards it as a universal set of rules about how to reach agreement on whether scientific statements are true or false on the basis of

impartial observational evidence. Rather, rationality, as noted by Halfpenny (1991: 213), came to describe:

...a set of socially embedded practices for conducting arguments, a set of culturally specific norms for creating and contesting the credibility of knowledge claims. Universal rationality is replaced by a range of rationalities, each operating within and internal to a particular social group. In this relativist view, deductive logic, instead of being the essence of rationality, is itself a historically specific precipitate of a particular mode of life. It is one culturally conditioned conception of how arguments should be conducted, and it has no universal authority to legitimate the truth of knowledge claims.

Simply put, scientific knowledge came to be viewed as “social knowledge, that is, it is constructed through interactions among individuals ...A consequence of embracing the social character of knowledge is the abandonment of the ideals of certainty and of the permanence of knowledge” (Longino 1990: 231-232).

Therefore, the thrust of work in SSK is concerned with showing that the ways in which producing, maintaining, and modifying scientific knowledge claims are a local and mundane affair. In SSK, knowledge referred to ‘any collectively accepted system of beliefs’ or to “whatever people take to be knowledge...truth is simply identified with ‘the body of locally credible knowledge’ (Friedman 1998: 253). Understanding what it means for scientists to behave “logically” or “rationally,” how scientists come to recognize something as a “fact,” how the very idea of scientific knowledge is constituted; the social circumstances in which what is routinely regarded as a body of knowledge is produced, and the processes of its transmission and transformation in social life (Offer 1996) are all necessary resources of SSK.

I contend that because SSK draws attention to the discourse and day-to-day practices of scientists, how they negotiate and debate what counts as scientific knowledge (Vaughan 1999); because it reveals a wide range of social dimensions, actors and

processes as necessary conditions for making, holding, extending, and changing knowledge; and because it is “concerned precisely with what comes to count as scientific knowledge and how it comes so to count” (Collins 1983: 267), it was the appropriate theoretical framework for the study of the knowledge education production processes in the nanotechnology network.

Studying Scientific Networks in SSK

The term “network” is commonly used in social science to describe technological relations, economic forms, political structures and social processes (Murdoch 1998). Recently, science studies have also provided rich explorations of the social structures and networks shaping scientific controversy, and they have examined “laboratory life” in great detail. These recent efforts to develop a ‘new’ sociology of technology have resulted in a bombardment of new terminology (actor-networks, seamless webs, systems builders, and heterogeneous engineers) that attempts to explain the nature and structure of techno-scientific networks (Scott 1991). Such efforts to link the sociological study of science and technology to the concept of networks is not something new. As far back as 1962, Duhem argued that scientific statements or beliefs are connected in a network, and Lowe (2004) notes that Kuhn (1970) also saw the web of belief as being tied to scientific communities and their practices. In this way it was possible to see the web as a network embodied in the knowledge and practices of specific groups of scientists.

Furthermore, in her study of “invisible colleges,” Crane (1972) described how scientific knowledge grows through the diffusion of information within and among formal scientific communities and informal social communications networks. These networks emerged as links within a network were added or dropped, changing and

adjusting to internal and external factors such as research funding, realignment of institutions and technology innovations (Monge and Eisenberg 1987). This view of networks – that the place of technology and knowledge objects is deeply wound into the networks (Clegg 1995; Miller 1997) – is prominent within the SSK tradition. Below, I identify and describe the various SSK approaches to studying scientific networks that proved relevant to this case study.

The Strong Programme

Drawing from conflict sociology, early approaches in SSK began with a focus on the construction of scientific theories as outcomes of agnostic relationships among scientists. By the mid-1970s, a group of researchers in Edinburgh (Bloor, Barnes, Edge, MacKenzie) developed the founding documents for a new SSK macro-analytic approach called Bloor's Strong Programme⁷. One empirical research tradition associated with this Programme was interests studies or the analysis of scientific controversies from the perspective of social interests and values in science (Rehg 2000).

Examples of interests studies include Andrew Pickering's (1984) study on competing professional interests, and Steven Shapin and Simon Shaffer's (1985) study on the controversy between Robert Boyle and Thomas Hobbes about experiments with vacuum pumps. In interests approaches, scientific controversies are strategic anchoring points for the study of consensus formation, that is, the mechanisms by which knowledge claims come to be accepted as true. Essentially researchers attempt to show that interests shape social action. This, I found to be relevant to this case study since these inquiries show how technoscientific actors produce interested supporters into scientific networks through patterns of scientific funding and research priorities.

Empirical Programme of Relativism (EPOR)

Associated with Harry Collins (1981, 1983, 1985), another major approach to SSK is the Bath School, which examined controversies and focused on microsociological processes using observational methods. Commonly referred to as the empirical programme of relativism or EPOR, it highlighted three stages: first, demonstrate the “interpretative flexibility” of experimental results, i.e., their ability to be subject to more than one interpretation; second, analyze the mechanisms by which closure is achieved; and third, link the mechanisms of closure to the wider social structure. To understand the mechanisms of closure, Collins focused on the “core set” of experts and laboratories, which involved a temporary network of conflicting individuals and networks. Thus, the “core set” is an important concept which contributes to the study of scientific networks in SSK.

Social Construction of Technology (SCOT)

Originally outlined in Bijker and Pinch (1987) and Bijker (1987), the SCOT program was aimed at a reversal of the tendency to separate the social study of science and the social study of technology by applying the same principles formulated by Collins’ EPOR to the study of the technological artifact. SCOT follows more or less the same stages of EPOR (Leydesdorff 1991), except Bijker and Pinch replace the term “core set” with “relevant social group” and “closure” with “stabilization.” SCOT is also helpful in understanding techno-scientific networks through important concepts like relevant social groups, stabilization and technological frames (Evans, Guy and Martin 1999). Firstly, the term “relevant social group” can be synonymous with Collins’ “core set,” and is therefore another network concept.

Secondly, in SCOT, technological artifacts and scientific practices are best seen as the constructions of individuals or collectivities that belong to relevant social groups, or “socially constructed cultures” (Bijker and Pinch 1987). Because these social groups have different interests and resources, they tend to have different views of the proper structure of artifacts. Accordingly, the stabilization or “closure” of artifacts is explained by referring to varying social interests that are ascribed to the groups concerned and their differential capacity to mobilize resources in the course of debate and controversy. Closure is achieved when debate and controversy about the form of an artifact is effectively terminated.

Finally, the concept of technological frame refers to the ways in which relevant social groups attribute various meanings to an artifact or as Bijker (1987: 168) puts it, “a technological frame is composed of...the concepts and techniques employed by a community in its problem solving...This makes [it] into a combination of current theories, tacit knowledge, engineering practice..., specialized testing procedures, goals, and handling and using practice.” Frames are located between actors and thus, structure the interaction of members of a social group. Different actors will have different degrees of inclusion in the frame, and actors, in principle could be members of more than one technological frame. Furthermore, the inclusion of actors in a technological frame can be specified by describing their goals, problem-solving strategies, experimental skills, theoretical training, and so on.

Laboratory Studies

During the late 1970s and early 1980s, an alternative to the Edinburgh interests analysis emerged in the form of constructivist approaches that emphasized the technical

details of scientific work (Owen-Smith 2001). These micro-analyses or laboratory inquiries relied on the observational study of scientists in the laboratory (Clarke and Fujimura 1992; Knorr-Cetina 1981; Latour and Woolgar 1979; Lynch 1984) and held the view that knowledge emerged from practice, from repeated, everyday experiences. The stuff of the social is not only human, rather it is embodied in a variety of material forms – a talk or conference presentation, papers or skills of scientists and technicians – which all contribute to the patterning of the social. Researchers rejected the implied separation of social context and scientific practice, and featured ethnographic studies in which they traced the network of activities and interactions that result in the production and acceptance of a scientific fact. Examples of these studies include Karin Knorr Cetina's (1981) year-long study of a plant science laboratory at UC Berkeley, and Bruno Latour and Steven Woolgar's (1986) study of the neuroendocrinology laboratory at the Salk Institute.

One of the most influential developments in this area of SSK came from Knorr-Cetina's idea of "variable transscientific fields" where she extended the concept of networks beyond scientific communities or specialty groups from a limited group of discipline-bound or problem-bound colleagues, as in Collins' "core set," to something more flexible and heterogeneous. She (1981: 132-133) posed that "the scientists' practical reasoning routinely refers not only to specialty colleagues and other scientists, but also to grant agencies, administrators, industry representatives, publishers, and the management of the institute at which they work. In short, laboratory reasoning and involvements in which scientists perceive themselves to be entangled refer us to symbolic

relationships which are transepistemic, that is, to relationships which in principle go beyond the boundaries of a scientific community.”

Social Worlds Theory

Another largely microsociological framework that emphasized laboratory practice was social worlds theory. A social world is a unit of discourse “not bounded by geography or formal membership ‘but by the limits of effective communication.” Like laboratory studies, social worlds analysts advise against assuming distinctions between content and context, inside and outside (Kleinman 1998). For instance, Clarke and Fujimura (1992) suggest that the realm of the laboratory is inseparably linked to other “worlds”: “the world is in the laboratory and the laboratory is in the world” Fujimura (1996:11). Fujimura further shows how scientists negotiate disparate demands from different social worlds, highlighting the ways in which “boundary objects”⁸ (Star and Griesemer 1989) and “standardized packages”⁹ (Fujimura 1987, 1988, 1992, 1996) make possible cooperation between social worlds. To achieve success, scientists must find problems that crosscut or align different social worlds.

Fujimura also introduced the idea of a scientific bandwagon, which occurs when large numbers of people, laboratories and organizations commit their resources to one approach to a problem; much like the idea that researchers tend to flock to the “hot” areas in science and technology. She argues that the success of the bandwagon is due to several factors, including a theory-method package that made “doable” problems possible, the existence of new techniques, the realization that novel information could be rapidly produced, and the support of funding institutions. The bandwagon concept is

consistent with network theories as it can be viewed as a particular type of network growth.

Network Theories

Thus far, we have seen that the agnostic alliances of Bloor, the core set and relevant social groups of the EPOR/SCOT programs, the transscientific fields of Knorr-Cetina, and the social worlds of Clarke, Fujimura and Star are all examples of attempts to think about the social units of science – the laboratories, departments, research institutions, discipline and so on – in terms of networks. However, perhaps, the best known development of the network concept is the work of Thomas Hughes (1983). In keeping with other constructivist approaches like laboratory studies and social worlds theory, according to MacKenzie (1987), Hughes refused to deal separately with the technological and the social.

Using the growth of electricity supply systems, Hughes showed that successful system builders simultaneously had to engineer technological, economic and political matters into what he referred to as a “seamless web”; a concept which explicitly conveys the idea of a techno-scientific network. He also recognized an exogenous environment that can influence systems or that systems can in turn control. “Successful system builders cannot work with a rigid demarcation between the system and the environment in which the system develops” (MacKenzie 1987: 196-197). Summarizing Hughes’ formulation of systems, Law (1987: 121) noted:

System builders seek to create a network of heterogeneous but mutually sustaining elements. They seek to dissociate hostile forces and to associate them with their enterprise by transforming them. The crucial point, however, is that the structure of the network reflects the power and the nature of both the forces available and the forces with which the network collides. To say, then, that an artifact is well adapted to its environment is to say that it forms a part of a system or network that is able to assimilate (or turn away) potentially hostile external

forces. It is, consequently, to note that the network in question is relatively stable. Hughes emphasized that systems or networks are constructs that should not be taken simply as given. In some cases, systems may encounter “reverse salients” or “components of a system that have fallen behind or out of phase with the others”; which Hess (1997: 107) called “something like bottlenecks in a network.” Hughes shows that systems or networks will only hold together so long as the correct conditions prevail.

Actor Network Theory (ANT)

Another sustained and detailed attempt to theorize networks is the actor-network approach of Bruno Latour, Michel Callon, John Law, and their followers (Callon 1987; Latour 1987), which I describe at length in Chapter Three as the most suitable analytic-methodological perspective for investigating knowledge education production processes in the nanotechnology network. I will however make some brief comments here about ANT as it pertains to its relevance to studying scientific networks in general. Arising primarily out of poststructuralism, Saldanha (2003) points out that ANT has had tremendous influence in science studies (Latour and Woolgar 1979; Latour 1987; Latour 1999a), the history of technology (Law 1986; MacKenzie and Wacjman 1985; Shapin and Schaffer 1985) and the sociology of medicine (Latour 1988; Berg and Mol 1998).

Burgess, Clark and Harrison (2000) also point out that ANT has been extended beyond the production of science to contexts and situations that lie outside of, but intersect with scientific networks (Clark and Lowe 1992; Murdoch 1994; Clark and Murdoch 1997). It has found affinities in anthropology (Strathern 1991), market economics (Callon 1998), feminist ‘technoscience’ studies (Haraway 1997), human geography (Thrift 1996), organizational sociology (Chia 1998; Clegg 1989), social psychology (Michael 1996), cultural studies (Kendall and Wickham 2001), media studies

(Couldry 2000), political theory (Barry 2001), sociology of globalization (Urry 2000), sociology of tourism (Saldanha 2002), and the philosophy of science (Pickering 1995; Stengers 1997, 2000).

Consistent with the more radical form of SSK, which suggests that the objects of science are constituted in and through practices, and in keeping with the micro-analytic or ethnographic laboratory inquiries, ANT uses direct observation of the actual site of scientific work, including the inscriptions (documents, images, graphics, and so on) that scientists use and create (Latour 1987) to examine how objects of knowledge are constituted in science. It deals directly with the systematic investigation of knowledge production processes through laboratory practice and equipment, and it employs the use of language, discourse, texts, tools and other methods and instruments, as part of the field in which investigation occurs (Maynard and Schaeffer 2000).

ANT can be seen as an attempt to extend Hughes' systems metaphor even further by breaking down the distinction between human actors and natural phenomena. In many instances, 'system' and 'network' are used interchangeably. But, in ANT, there is a clear distinction: "a system...has an environment – a remaining outside – that a network does not. The organizers of networks leave nothing outside, or to chance that would affect the network" (Hughes 1986: 290). The social and the natural are both treated as elements in actor networks and are associated by means of networks. Context and content are not distinct but instead the mutual products of networks. Facts and technologies flow along networks and as networks expand and become more robust, knowledge claims become more accepted and technologies more successful.

In this SSK approach, knowledge is seen as a product of a network of heterogeneous materials “...which range from people, through skills to artifacts and natural phenomena” (Law 1987: 107). Science is viewed as constructed through actors and their networks, negotiated in social settings imbued with power relations (Dea and Scoones 2003). And, scientific knowledge is conceived as part of a “seamless web” incorporating social, political and ideological dimensions along with the conceptual content of science (Hughes 1983). Thus, ANT not only reveals that social and material processes are seamlessly entwined within complex sets of association (Murdoch 1998), but in so doing, brings attention to the presence of conflict and negotiation in shaping scientific networks.

In sum, we can deduce several insights that SSK brings to the study of techno-scientific networks and to this case study. The SSK approaches described in this section reveal that networks are constructed out of the alignment or interests of social, scientific and technological orderings; that the techno-scientific network is a web that can include humans as well as creations of science. The network is not static but changes; it is relational; it invites multiple kinds of relationships: oppositional, associative, conditional, simple, complex, ordered, chaotic; and it is dynamic, needing to be sustained as it may be constantly challenged by other networks. According to Fountain (1999), through the metaphor of the network, one is able to map what relations are upheld and to what degree these relations are upheld when controversy arises.

¹ See Feynman, R.P. December 1959. “There’s Plenty of Room at the Bottom: An Invitation to enter a new field of physics” at www.its.caltech.edu/~feynman or www.zyvex.com/nanotech/feynman.html

² Additional examples of the “inevitability of progress” rhetoric include:
The Committee on Science Hearings:

Our rapidly growing ability to manipulate matter and energy at ever smaller scales promises to transform virtually every sector of society, including health and medicine,

manufacturing, electronics and computers, energy, travel and defense. The golden age of nanotechnology, is therefore, a couple of decades away. This era will bring us the ability to essentially convert software...directly into physical products. We will be able to produce virtually any product for pennies per pound. Computers will have greater computational capacity than the human brain... With the advent of nanotechnology, we will be able to keep our bodies and brains in a healthy, optimal state indefinitely. We will have technologies to reverse environmental pollution. Nanotechnology and related advanced technologies of the 2020s will bring us the opportunity to overcome age-old problems, including pollution, poverty, disease and aging (Kurzweil 2003).

The Christian Science Monitor

Scientists here at Washington University and around the country believe such experiments in nanotechnology could one day change the world. By building machines and materials with atomic precision, researchers believe they'll create faster computers, lighter spacecraft, and airplane wings so efficient they'll adjust to airflow like a flexible skin. Medical robots would snatch a page from science-fiction's "Fantastic Voyage" and travel through the body fixing things. Computer components the size of a molecule could put a supercomputer into the palm of your hand (Belsie 2000).

³ The following is an excerpt from Clinton's speech consistent with the endless frontier rhetoric: "Today, as the first light falls on the new millennium, we see illuminated before us an era of unparalleled promise – fueled by curiosity, powered by technology, driven by science. Our restless quest to understand the unknown, a quest that has defined us as Americans since the first explorers set foot on this continent, will quicken. More than any other time in human history, the 21st century will be the century of discovery and science" (www.mrs.org).

⁴ The following is an excerpt from Senator Mikulski consistent with the endless frontier rhetoric: "We started the last century with the industrial revolution and ended it with the information revolution. Now, at the beginning of the 21st century, we are on the verge of a new revolution – THE NANOTECHNOLOGY REVOLUTION...In Nanotechnology, we are poised to take the next major leap into the future where the possibilities are endless. Now, the time is right to establish Nanotechnology as an urgent national priority" (Roco, Williams and Alivisatos 1999: 272).

⁵ Additional examples of the "social utility" rhetoric include:

The Bulletin of Science, Technology and Society

Nanotechnology are examples of newly developing technologies that hold the potential to radically alter the fundamental nature of human biological life. The quests for enhanced brains, eradication of disease and even, the indefinite extension of human life are actually imaginable today within the realm of technological ingenuity (Berne 2003: 88).

The 2003 House Committee on Science Hearings:

Medical uses: molecular machine systems will be able to sense and rearrange patterns of molecules in the human body, providing the tools needed to bring about a state of health, regardless of a disease's cause;

Environmental applications: it will be possible to construct our products with zero chemical pollution, recycling leftover molecules;

Raising sustainable living standards: it will be able to cleanly and inexpensively produce high-quality products using common materials and solar energy;

Expected economic and military advantages are driving a technology race already underway (Peterson 2003).

The Futurist

A host of resilient technologies based on...nanotechnology will help us adapt to environmental extremes. For humanity to be truly sustainable we must protect ourselves from natural catastrophes that exterminated the dinosaurs and other species in the past. Nanotechnology, biological engineering, and terraforming as planetary defense tools and

that makes superdisaster preparation cheaper, more portable, and profitable (Mulhall 2001).

New Voices in Chemistry

Projected demands on natural resources significantly exceed Earth's resource base and thus threaten our environment and our way of life. Given the central role of chemical products in modern societies, the development of sustainable chemical practices is essential to avoid depleting our natural resources and damaging our ecosystems.

Chemists must invent and develop sustainable chemical practices if our environment and economies are to thrive in this century. Controlling properties at the molecular level is a key to success in both nanoscience and green chemistry (Hutchison 2003).

⁶ Vannevar Bush, a respected engineer and science administrator who headed the government's wartime Office of Science Research and Development was a leading science spokesman during the early 1940s. He led the drive to build the first atomic bomb, organizing the Manhattan Project and setting the stage for every U.S. Big Science project from the H-bomb to the Moon race and Star Wars. He conceived the National Science Foundation and the Advanced Research Projects Agency, helping guarantee U.S. dominance in cutting-edge technologies by channeling federal funds to new enterprises. Bush's 1945 famous *Science – The Endless Frontier* report argued strongly for the concept of continued government support of science (National Science Foundation 1994).

⁷ The following are the basic tenets of Bloor's Strong Programme: causality, that is, social studies of science would explain beliefs or states of knowledge; impartiality, that is, SSK would be impartial with respect to truth or falsity, rationality or irrationality, or success or failure of knowledge; symmetry, that is, the same types of causes would explain true and false beliefs; and reflexivity, that is, the same explanations that apply to science would also apply to the social studies of science.

⁸ The notion of 'boundary objects' accounts for how a link can be forged between various and highly differing communities of actors that allows them to communicate and collaborate. According to Star and Griesemer (1989: 393), they are "objects which are both plastic enough to adapt to local needs and to the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites... These objects may be abstract or concrete". Thus, drawings, sketches and models work as boundary objects. It is the 'plasticity' of boundary objects that helps facilitate the coordination and management work across different social worlds.

⁹ Standardized packages are more robust than boundary objects, changing practices on both sides of the boundary. They are common products used by actors on both sides of the border to meet their own purposes.

Chapter Three : FOLLOWING THE ACTORS THE METHODOLOGY OF NETWORK CONSTRUCTION

Networks pervade every aspect of our lives. Just consider our nervous system. It is an organized network of nerve cells, and these cells themselves are networks of molecules connected by biochemical reactions. Our society can also be seen as a network – a collection of people linked by familial relationships, friendships and professional ties. Furthermore, the tools and technologies we use such as the Internet, the light switch and the roadways are but a few examples of networks. In practice, these networks I have identified, like other networks, can be represented as a set of points or nodes denoting people, institutions and/or artifacts, connected by lines that denote acquaintance, agreements, exchanges and/or interactions. So, it is quite possible for someone to map or construct a network for a community, organization, school or university and so on.

In this chapter, I delineate the methodology or, as Deely (1990) poses, the philosophical framework or ‘point of view’ within which a set of methods can be systematically applied (Guba and Lincoln 1988) to the construction of the nanotechnology network. I utilize the actor-network approach as the theoretic-methodological tool-kit for outlining and describing the arrangement of elements that constitute the relations from which nanotechnology emerges. I also identify the processes within the nanotechnology network that I investigated and provide an account of the strategy of inquiry and data collection techniques used in this study.

Actor-Network as Theory

Proposed by Bruno Latour, Michel Callon, and John Law, actor-network theory (ANT) has its origins in network studies of interdependent social practices that constitute

the work of science and technology. It is a theoretical approach within the sociology of scientific knowledge (SSK) that helps to structure and explain links between society and technology, with primary foci on the actors and how they are involved in the shaping of technology. At the heart of ANT's development is the study of the heterogeneous character of technology and scientific knowledge. As Law (1999: 4) puts it, "I simply want to note that actor-network theory may be understood as a *semiotics of materiality*. It takes the semiotic insight, that of the relationality of entities, the notions that they are produced in relations, and applies this ruthlessly to all materials - and not simply to those that are linguistic."

Theorists of this ilk hold the view that the content of science is constructed along with the social structure and relations: "scientific knowledge is considered not an individual achievement but as interactively achieved" (Zuckerman 1988: 554). Content and context co-constitute and mutually shape each other in what is referred to as a "seamless web" (Hughes 1983). In ANT, networks are "the stuff out of which both individual identity and social organization are constructed" (Fuller 2000: 12). Following the work of Thomas Hughes, ANT insists that "the stability and form of artifacts should be seen as a function of the interaction of heterogeneous elements as these are shaped and assimilated into a network" (Law 1987: 113). It therefore attempts to explain stabilization processes of technical and scientific objects as these results from the building of actor networks (Callon 1987; Latour 1987; Callon and Latour 1992).

There are a number of features that constitute ANT. First, the actor-network refers to a particular configuration or construct that indicates relationships between actors (Latour 1979, 1987, 1993, 1999b; Callon 1986, 1991; Akrich 1992). According to Callon

(1987: 93), an actor network is “simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what is made up of.” The actor network, therefore, represents a shifting system of alliances and exchanges in which both humans and nonhumans are nodes to be explained (Mol and Law 1994).

Based on its principle of symmetry, actor networks can be characterized as heterogeneous networks or techno-economic networks (Callon 1991), collectives of humans and nonhumans (Latour 1991), patterned networks of heterogeneous materials (Law 1992), or hybrid collectives (Callon and Law 1995). Such networks may include companies, government departments, social groups, consumer organizations, standardization bodies, regulators, on-line systems, software, and so forth. In the actor network, each actor has the ability to act – to make certain things easier and others harder thereby changing the overall constellation of the network.

There is no essential separation between human and nonhuman – between us and our tools and technologies. Even technological artifacts are actors with multiple purposes and can act in ways that complement and/or extend humans (Latour 1992). Thus, ANT allows for technical machines, devices and natural forces to be “actants”¹ in networks. According to Latour, we must negotiate with machines just as with people. We need to recruit them as allies, to authorize and notify them, and to mobilize and delegate them. The ability to act is, however, not innate in any actor, but is a consequence of his, her or its position in the network. When actors and their interactions are taken together, they form a network.

Second, the construction of networks is a process of developing coherence between multiple actors. The basic metaphysics of ANT is the view of science as a field of human and nonhuman agency, both associating with each other and evolving together in networks. In other words, in the lab, scientists are engaged in the simultaneous reconstruction of social contexts of which they form a part – “laboratories simultaneously rebuild and link the social and natural contexts upon which they act” (Callon 1986: 20), thereby forming networks. The work of scientists involves the juxtaposition and enrolment of heterogeneous elements – rats, test tubes, colleagues, journal articles, funders, grants, papers at scientific conferences, etc. – that require continual management. As Pickering (1995: 21) puts it, scientists are “human agents in a field of material agency which they struggle to capture in machines.”

ANT therefore stresses that no one acts alone. Engineers and scientists enrol resources of all kinds – knowledge, equipment, data, money, publicity, power and so on – into networks to get their projects done. For example, White’s (1999) work on Sir Isaac Newton reveals that the scientist did not act alone in creating the theory of gravitation. He needed observational data from the Astronomer Royal, John Flamsteed. He needed publication support from the Royal Society and its members. He needed the geometry of Euclid, the astronomy of Kepler, the mechanics of Galileo, the rooms, lab and food at Trinity College, an assistant to work in the lab and more. This can be said of any scientific or technological project. Being able to incorporate and merge different actors into a bundle of socio-technical relationships is essential to the task of network construction.

Third, the actor network approach emphasizes the dynamic character of heterogeneous networks of aligned interests. It introduces concepts of power and politics to characterize network relationships (Fountain 1999), that is, the social exchanges and political processes necessary to enrol interested parties in the building and use of technologies. This is particularly important for nanotechnology. Nanotechnology is a relatively “young” field that lies between several disciplines. Nanoscientists and technologists are continually enmeshed in relationships both within and outside their disciplines. They come from distinct disciplinary backgrounds – biology, chemistry, physics, engineering, to name a few – that require constant negotiation with other groups. These relationships between the different groups in nanotechnology cannot simply be reduced to one network but consist of multiple networks with different degrees of alignment and enrolment.

Through a concept called translation² (Callon, 1986; Latour 1987; Law 1992; Latour 1997), ANT explains how these multiple actors come to collaborate. According to Singleton and Michael (1993: 229), translation refers to “...the means by which one entity gives a role to others”; that is, the means “whereby one thing represents another so well that the voice of the represented is effectively silenced” Fuller (2000: 13). Translation rests on the idea that some actants or actors in a network will try to force or enrol others into positions that suit their purposes. “By translation we understand all the negotiations...acts of persuasion and violence thanks to which an actor or force takes...authority to speak or act on behalf of another actor or force” (Callon and Latour 1981: 279).

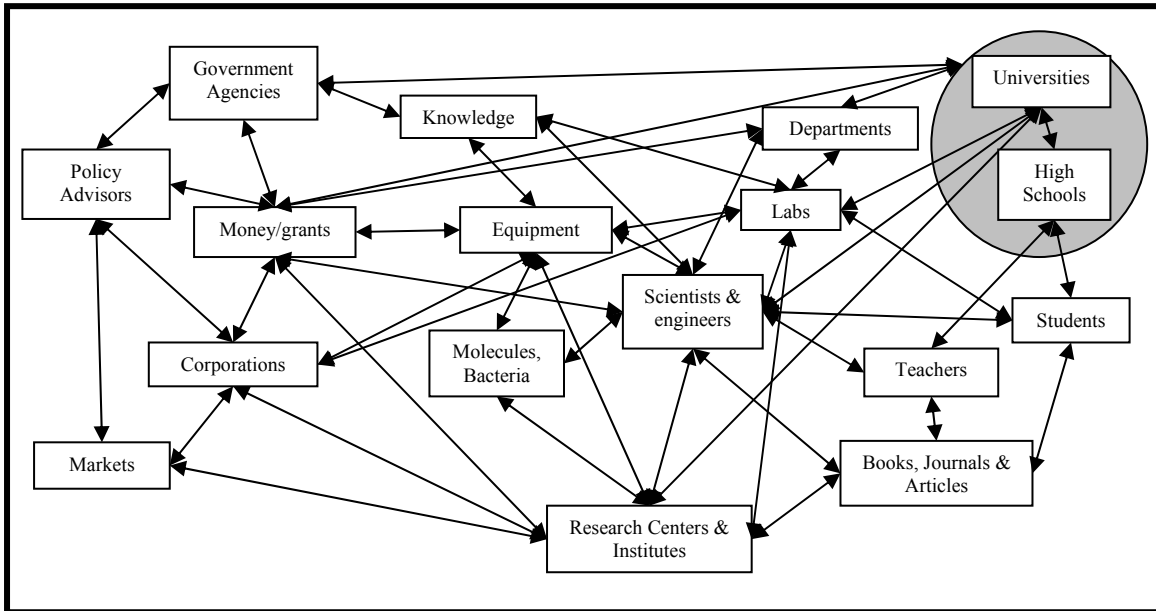
When it comes to interactions between human actors, translation parallels notions of persuasion and negotiation of common interests, and between humans and objects, it occurs when the object is imparted with its purpose in how it interacts or affects other actors (Akrich 1992). The ‘sociology of translation’ therefore helps to explain the transformation of actors as they are enrolled and mobilized in the network. “The more allies one has managed to enroll, and the stronger the links one has established among them, the more difficult it becomes for others to challenge one’s domination” (Amsterdamska 1990: 499). Simply, ANT holds that scientific networks are comprised of and influenced by human and nonhuman actors. As more actors are enrolled to support scientific claims, the size of the network expands. It is this growth that provides the basis for credibility and legitimacy of claims and that sustains the integrity of the network. This theoretical perspective grounds the research questions under investigation in this case study on nanotechnology.

Actor-Network as Method

Scientific networks connect people to machinery, machinery to things, things to funding committees, committees to articles in journals which are written by people and so on. Consequently, for any organization or phenomenon being studied, one must first generate its network by mapping the nodes (interactions among actors) and links (connections among the nodes) that comprise the network. In approaching nanotechnology as an actor-network, I found that there were many elements that were enrolled, mobilized and translated as actants into the network. There were scientists and engineers from several disciplines, machines and instruments, government agencies, standardization bodies, universities, businesses, research institutions, policy advisors and

regulators, teachers, labs, computers, articles, websites, journals, molecules, bacteria, money, grants, contracts, experience, skills and knowledge, and so on. The relational actor-network map below (Figure 3.1) illustrates a part of the complexity and context of the actors and interactions that constitute nanotechnology.

Figure 3.1 The Relational Actor-Network Map of Nanotechnology



As the actor-network map suggests, ANT goes beyond the simple configuration or tracing of actors, activities and interactions in networks. It shows how important it is to the stability of the nanotechnology processes that all connections be aligned and translated in the network. Furthermore, ANT helps explain the processes by which nanotechnology becomes accepted and taken up by new groups. It explores the ways that the networks of relations are composed, how they come into being, how they are constructed and maintained, how they compete with other networks, how actors enlist other actors into their world and how they bestow qualities, desires, visions and motivations on these actors (Latour 1996).

ANT allows us to address pertinent questions that help us understand the course of a project or enterprise such as nanotechnology:

- What actors, interests and motivations are enrolled in the network?
- How actors' values, interests and motivations influence the size of the network?
- How changing alliances and alignments of actors affect the size of network?

ANT therefore offers a rich analysis of the actors involved in nanotechnology and how the nanotechnology network is being constructed and maintained.

Methodologically, ANT offers practical tools for the task of constructing networks. Latour (1999c: 20) himself poses that “far from being a theory of the social or even worse an explanation of what makes society exert pressure on actors, it always was, and is from its inception (Callon and Latour 1981), a very crude method to learn from the actors without imposing on them an *a priori* definition of their world-building capacities.” ANT consists of two methodological approaches.

The first, referred to as its methodological dictum, is to “follow the actors” (Latour and Woolgar 1979). Originating from micro-analyses or laboratory studies, this is an anthropological stance that focuses on contemporary scientific practice within the laboratory. It is based on “the premise that the social construction of knowledge begins there, and that it is where the constituent processes are most readily observed” (Zuckerman 1988: 553). This mode of network construction involves ethnographic studies of particular research groups, interviewing and observing actors and tracing the activities and interactions that result in the production and acceptance of science and technology.

It involves the researcher “following” scientists and engineers as they work to perform the construction of sociotechnical networks. He or she must describe the heterogeneous materials from which networks are composed by recording their interactions, connections and effects (Latour 1987). This also includes identifying degrees of participation and alliance building in networks, motivations for participating in conferences and associations and the role of technologies used by actors. Thus, to “follow the actors” means not only look at what they do, but also what interests them, and what they believe.

In ANT, nonhuman agency is best understood in terms of semiotics. Thus, the second methodological approach is to examine inscriptions that are central to knowledge work. Some theorists (Latour and Woolgar 1979; Callon, Law and Rip 1986) argue that texts (including journal articles, conference papers and presentations, grant proposals, and patents) are among the major products of scientific work, and through the citations and references that support the research, they represent a variety of network associations. It is through the “literary inscription” that one is able to see all agents symmetrically. In texts, both human and nonhuman actants are constantly coming into being and fading; carrying work to other people and institutions; enrolling and mobilizing others. Texts also attempt to present work in such a way that its meaning and significance are irrefutable, and therefore they are central to the process of establishing credibility. In general, texts translate others, thereby building an actor-network.

However, inscription devices are not limited to the scientific text. They include images of many sorts, databases and the like. According to Latour (1987), an inscription is any object that records and thus, translates nature, particularly in a visual

representation. For example, nanoscientists and technologists use a variety of instruments, from force curves to atomic force microscopies (AFMs) and scanning electron microscopies (SEMs) that make nature ‘accessible’ through the inscription of measurements such as graphs, diagrams or illustrations. Taken together, all these inscription devices – texts, images, databases, etc. – can be objects that although they do not necessarily operate to define a network play an important supporting role in aligning networks.

Limitations and Criticisms of Actor-Network Theory

Although I have chosen ANT as my theoretic-methodological framework, I am aware that there are several limitations to what it can provide. First, critics have posed that the micro-analytic approach of carrying out analysis by following actors sets aside concepts of social structure (Winner 1993; Saetnan 1997; Doolin and Lowe 2002). Actor network studies often lack insights of the wider, i.e., the macro social contexts – the events, influences, etc (Martin and Scott 1992). Admittedly, ANT does explain how social relations are ordered to cause effects, but it leaves untouched an analysis of how social structures like inequality and power affect the ordering of social relations. In general, ANT neglects the role that institutionalized social structures play on localized processes of social interaction. Similarly, feminist critiques of ANT have pointed out that it fails to consider the role of social characteristics like gender, class and race.

Second, in their study of actor network theory and critical information systems research, Doolin and Lowe (2002: 73) identified “the symmetric treatment of humans and non-humans” as an area of ANT which has received much scrutiny and criticism. According to ANT critics, treating people and things equally reduces human agency and

tends to have a dehumanizing effect on human actors. This leads to producing actants that are “flat.” Saetnan (1997) also noted that giving actors equal weight is problematic when it comes to theorizing power relations.

Third, critics contend that there is a tendency in ANT to privilege one perspective: the viewpoint of the most powerful actors over the less successful ones. According to Amsterdamska (1990: 502), in ANT, “winning seems to be everything.” She further stated: “Are we prepared to agree with the conclusion that it matters not at all what we say and how we justify what we are saying so long as we make others believe us and manage to enroll them, no matter by what means and for what purpose?” If we are, then, as Winner (1993: 369) posed, ANT “does not allow us to look at the decisions that never land on the agenda”:

What about the groups that have no voice but that, nevertheless, will be affected by the results of technological change? What of groups that have been suppressed or deliberately excluded?...Which social groups have finally been sandbagged out of the laboratories and which social voices effectively silenced? It attends to the needs and problems of the powerful persons and groups: those with the resources to enter the game and define its terms.

In privileging the perspective of the powerful, ANT’s critics like Star (1991) claim that it reduces us to flattening accounts of how science and technology are constructed and developed: “an account of politics and society that is implicitly conservative” (Winner 1993: 369).

Fourth, Doolin and Lowe (2002: 73) pointed out that another limitation of ANT is its “moral relativism.” As Winner (1993: 372) further explained, it does not allow for “anything resembling an evaluative stance or any particular moral or political principles that might help people judge the possibilities that technologies present.” It does not take a stand on the larger questions about science, technology and society but remains

agnostic with regard to the good or ill attached to scientific and technological achievements. In failing to take a stand, ANT's "underlying leitmotif...is still (implicitly) that of progress."

Finally, with respect to its status, ANT has been criticized for its vagueness. There continues to be ongoing debates surrounding whether or not ANT is a theory, a methodology, a perspective, a vocabulary or an ontology (Walsham 1997; Law 1999). However, for this study, I relied on Law's (1999: 9) response to such criticism where he reminded us that ANT should not be taken as a fixed theoretical position but rather a "heterogeneous work in progress." And, as it pertained to critics who argue that ANT assumes that following the actors, reading the texts and listening to their conversations is a method that can efficiently reveal all there is to know about the sociotechnical world (Martin and Scott 1992: 488), as I stated in the preceding section, I chose to follow Latour's admonition to treat ANT as a "crude method."

For all its criticisms and limitations, one might wonder why use ANT as the theoretic-methodological framework in this study. Overall, I found ANT to be useful for this particular study because despite its limitations, it provided me with a number of conceptual and methodological tools (Martin and Scott 1992) suitable for studying scientific networks like nanotechnology:

1. It helps us understand how scientific networks are constituted.
2. It reveals that constant negotiation and renegotiation among and between actors.
3. Questioning conventional dichotomies between the social and technical is useful in showing that scientific networks are the result of enrolment and mobilization of what is usually called the social, technical, economic and political.
4. Although following the actors does not adequately explain why some oppose enrolment, it is still a good means of observing what methods have been used to construct the network or to block it.
5. It addresses an important concept of social structure – interests.
6. ANT's strength lies in its ability to provide an understanding of the particularities of individual cases such as the one under investigation in this study.

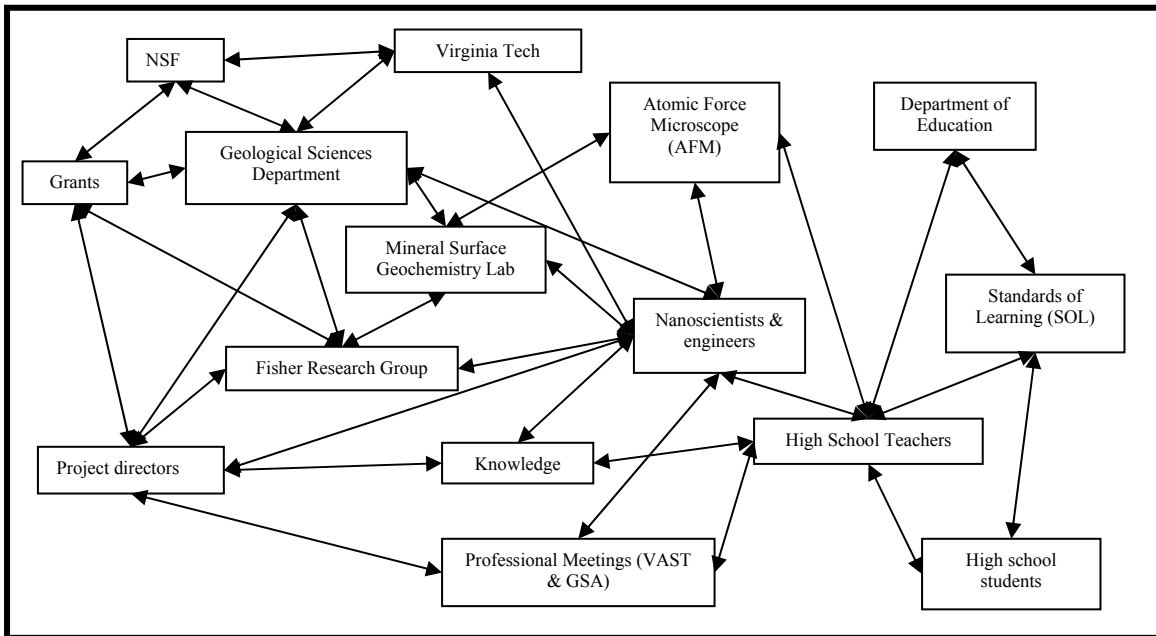
Where I do deviate somewhat from ANT in this study is my attempt to address some of the earlier criticisms on social structure and contexts by exploring the inevitable presence of conflict, power, hierarchy and authority, as well as the role of gender, race, actors' interests and motivations in scientific networks.

Shaping the Study

Ideally, applying the theoretic-methodological approach of ANT to the field of nanotechnology would mean that I would have to analyze all the nodes and links by examining all inscriptions and following all the actors, their activities and interactions in the relational actor-network map (Figure 3.1); a task which even at a glance appears to be time-consuming and impractical at this time.

Instead, I examined and analyzed a small section [the shaped portion in Figure 3.1 indicating interactions between the university and high school nodes] of the total actor-network – the knowledge-education production processes, which involved the enrolment of high school teachers into the nanotechnology network. The network map of the nodes and links depicted below in Figure 3.2 was determined through my participation, observation and interviews with participants in the Nanotechnology Curriculum Development Project (NCDP) over the two year period of this research.

Figure 3.2 The Relational Actor-Network Map of the Knowledge Education Production Processes



I conducted this research as a qualitative case study. According to Denzin and Lincoln (1994: 4), qualitative research emphasizes “the socially constructed nature of reality, the intimate relationship between researcher and what is studied, and the situational constraints that shape inquiry.” It scrutinizes social phenomena (Gubrium and Holstein 1997: 11-14), and helps us understand people from their own frame of reference (Taylor and Bogdan 1998). This research technique reveals the meanings people ascribe to particular events and activities, and to provide an understanding of complicated social processes in context (Esterberg 2002; Hoepfl 1997).

Although this study fit easily within this rubric, defining qualitative research was problematic. This is not surprising since Denzin and Lincoln (1994: ix-3) note that “the “field” of qualitative research is far from a unified set of principles...it has no theory, or paradigm, that is distinctly its own...nor does [it] have a distinct set of methods that are entirely its own” or “belong to a single discipline.” In fact, multiple theoretical paradigms claim use of qualitative research methods and strategies, from constructivism

to cultural studies, feminism, Marxism and others. Qualitative researchers employ several approaches, methods and techniques including “semiotics, narrative, content, discourse, archival, and phonemic analysis,” as well as “ethnomethodology, phenomenology, hermeneutics, feminism, interviews, ethnographies, survey research, participant observation, among others” (Denzin and Lincoln 1994: 3).

Notwithstanding its complexity, for this study, I defined qualitative research as any kind of research that produces findings about the “quality,” that is, “the what, how, when and where of a thing – its essence and ambience.” Simply put, it refers to “the meanings, concepts, definitions, characteristics, metaphors, symbols and descriptions” (Berg 2001:3) of the research problem or issue, that are utilized “to make sense of, or interpret, phenomena in terms of the meanings people bring to them” (Denzin and Lincoln 1994: 2). Such a research endeavor required that I look at situations using multiple lines of sight, referred to as “triangulation” (Berg 2001: 4). It also necessitated that I identify the principles that guide my work because as Guba and Lincoln (1994: 107) indicate, one cannot go about the business of inquiry without being clear about just what paradigm informs one’s approach.

Paradigm issues are crucial. They are worldviews, belief systems or principles that define the nature of the world or reality (ontology), the relationship between the researcher and the known (epistemology), and the ways in which we know the world (methodology) or gain knowledge of it (Creswell 1998; Denzin and Lincoln 1994; Esterberg 2002; Guba 1990; Kuhn 1970; Patton 1990). This research employed the constructivist paradigm, specifically, the social constructionism approach which aims to

understand the complex world of lived experience from the point of view of those who live in it (Halfpenny 1979; Schwandt 1994; Neuman 2000).

It assumes a relativist ontology (reality is socially constructed, subjective, multiple, socially and experientially based, local and specific); a subjectivist or transactional epistemology (researcher and subject(s) are interactively linked so that findings are literally created as research proceeds); and a naturalistic (inductive, contextual and dialectical) set of methodological procedures (Guba and Lincoln 1994: 110-111). As a social constructivist researcher, I had to “elucidate the process of meaning construction and [clarify] what and how meanings are embodied in the language and actions of social actors” (Schwandt 1994: 118).

Strategy of Inquiry

The case study as a strategy of inquiry holds a long, distinguished history across many disciplines. Its origin in social science can be traced to the anthropological work of Malinowski, and to case studies of the University of Chicago’s Sociology Department in the 1920s and 1930s (Creswell 1998). According to Creswell (1998: 61), the case study is “an exploration of a “bounded system” or a case (or multiple cases) over time through detailed, in-depth data collection involving multiple sources of information rich in context,” that is, situating the case within its physical, social, historical, and/or economic setting. I found the case study to be very appropriate because it drew attention to what specifically could be learned from the single case, rather than what could be generalized. Moreover, Stake (1994: 242) notes that it “...emphasize[s] objective description and personalistic interpretation, a respect and curiosity for culturally different perceptions of

phenomena, and emphatic representation of all local settings – all blending...within a constructivist epistemology.”

The Case

While some consider “the case” as a methodological approach that incorporates a number of data-gathering measures (Hamel, Dufour and Fortin 1993; Merriam 1988), Stake (1994: 236) contends that it is “not a methodological choice, but a choice of object to be studied. We choose to study the case.” My case consisted of the Nanotechnology Curriculum Development Project (NCDP) workshops held by nanoscientists in the Geosciences Department located at Virginia Tech, collaborating with high school teachers from surrounding Virginia areas.

There are several reasons for choosing to study a case. For example, the case may show different perspectives on a problem, process or event; it may be an unusual or ordinary case; or it may be intrinsically fascinating to the researcher. To be sure, my choice of this case began when I first heard the word “nanotechnology.” I became curious about exactly what is important about nanotechnology within its own world, its issues, contexts, and interpretations. Thus, this research initially began as an intrinsic case study because the case itself, on account of its uniqueness, interested me.

One might also choose a case because it provides some insight into an issue or it refines a theory, referred to as an instrumental case study. Here, the case itself becomes of secondary importance, merely serving a facilitative role for understanding something else like some theoretical question or problem (Berg 2001). Thus, what started out of mere curiosity about nanotechnology developed into an opportunity for me to examine more fully the socially constructed nature of scientific facts and technological artifacts in

the nanotechnology world. I saw my case as being not only suitable for such an endeavor, but also as having the potential to yield rich, detailed and in-depth data (Berg 2001). I felt that the web of social relations between Virginia Tech's nanoscientists and high school teachers, the variety of activities and events over the life of the project would provide rich and interesting data.

Admittedly, another reason for choosing this case was accessibility. My role as evaluator on a project held on my college campus afforded me close geographic proximity and easier access opportunities to spend substantial amounts of time with participants at relatively little financial costs to me. There were, however, some potential setbacks to being in the dual role of evaluator and social researcher. While I was privy to several sources of data, I fully acknowledge that I was being paid to monitor and advance the progress of NSF's project objectives. As such, my advice and recommendations ultimately affected the actors, events and processes that I was attempting to study.

The number of participants of my study was five nanoscientists, two project directors and six interdisciplinary science teachers from nearby high schools in the Virginia area, which I felt, was both reasonable and manageable. These participants were recruited in Spring 2002 through the NCDP conducted by the Geosciences Department. While I did not specifically engage in any recruitment techniques to arrive at the number of participants, gaining access to the case involved several steps. For a case study, Creswell (1998) notes that "gaining access through the gatekeeper and establishing rapport" are important. Thus, upon choosing my case, I verbally requested permission from a number of gatekeepers, that is, individuals who had formal or informal authority to control access: two directors and the lead research investigator. Once granted, I

obtained institutional review board (IRB) approval and formal written consent from participants in accordance with IRB rules and procedures.

To build rapport, a researcher must be conscious of self presentation as it influences relations in the field. Initially, I presented myself as an outsider – a mere observer. As participants became more familiar with me, I then presented myself in an informal, casual manner indicating my willingness to share their experiences, yet maintaining a respectful and attentive style in my interaction. While this aided in establishing rapport, I was aware that my own personal characteristics and feelings (Neuman 2000: 352), as well as my position as paid evaluator, had effects on my case outcomes. For instance, being employed by the gatekeepers posed problems in data collection for my research. There were some questions or issues that I was unable to openly ask or address with participants, and there were some information I was unable to divulge in the final reporting of my data.

On a personal level, as a black female, mindful of social research that has demonstrated science to be traditionally a white male domain (Keller 1985; Bleier 1986; Martin 1987; Haraway 1991; Harding 1993), I began my observations with the expectation that I should not expect a lot of diversity when it came to the racial and gender composition of the workshop participants. Of the seven (7) university faculty members, three (3) were female (one project director, one graduate student nanoscientist and one faculty nanoscientist), and of the six (6) high school teachers, two (2) were male.

As a sociologist, I also brought to bear views about science, its nature and practice based on my research orientation. To enter the world of nanotechnology without being preoccupied with “the social” is like asking a mathematician to develop an algebraic

formula without using numbers. So I set foot in this arena with a sociological outlook notably Blumer's symbolic interactionism perspective, which holds that humans act toward things based on the meanings those things have for them; that the meanings of things arise out of social interaction; and that meanings are created and changed through a process of interpretation. This perspective provided guiding principles for my own conclusions about what I saw, heard and recorded in this study.

Then, as a social researcher with very little background in natural science disciplines, and specifically in nanotechnology, I was a bit apprehensive at first about my ability to delve so deeply into a topic with which I had no familiarity. Although contested, Bodgan and Taylor (1975: 28) recommend that "...researchers choose settings in which the subjects are strangers and in which they have no particular professional knowledge or expertise." I argue that by choosing this "alien" terrain, also consistent with Latour and Woolgar's (1986) notion of anthropological strangeness, it enabled me to see social relations and events in new ways, through the eyes of a total newcomer. I, therefore, took comfort in C. Wright Mills' (1959: 232) comment that "you do not really have to *study* [i.e., to be trained in] a topic you are working on...once you are into it, it is everywhere."

Data Collection Techniques

According to Stake (1994: 242), a qualitative case study is characterized by the main researcher spending substantial time, on site, personally in contact with activities and operations of the case, reflecting and revising meanings of what is going on. What researchers are unable to see for themselves is obtained by interviewing people who did see or by finding documents recording it. It involves "the widest array of data collection"

(Creswell 1998: 123), comprising multiple sources of information such as interviews, observations, documents and audio-visual material (Creswell 1998:36) to provide an in-depth case picture. Consistent with Yin's (1989) listing of data gathering techniques and my theoretic-methodological frame (ANT), this research included the following: interviews, direct and participant observations, documents, archival records and physical artifacts. My intent was to convey through this matrix of multiple sources the complexity and richness of the case. Data collection began in the summer of 2002.

Interviews

I used two types of interviews: the semi-standardized interview and the guided focus group interview. For the former, I prepared an interview schedule (Appendix A) which was administered to nanoscientists and project directors at the inception of the workshop. In-depth tape-recorded interviews that varied from forty-five minutes to an hour were conducted and transcribed to obtain information about participants' attitudes and feelings about nanotechnology and their involvement in the project. Due to time constraints and conflicts, I was unable to interview high school teachers before the first workshop in June 2002 started. I conducted focus group interviews with nanoscientists on the last day of each workshop.

During the interim between the 2002 and 2003 workshops, I conducted face to face interviews with high school teachers to obtain information about their motivations for joining the project and their thoughts and feelings about their nanotechnology and their involvement. At the end of the second workshop held in July 2003, I conducted focus interviews with both nanoscientists and teachers, as well as in-depth interviews with project directors. These interviews helped provide valuable information about

participants' thoughts and feelings about the project, involvement in assigned activities, and interactions between nanoscientists and high school teachers. Telephone interviews with teachers were also conducted a few months following each workshop and I made periodic check-ins via email and in-person with project directors and nanoscientists to gauge the level and nature of their continued involvement in the project.

Direct and Participant Observations

There were limits on how much I learned from what people said in interviews. Sometimes, to understand more fully the complexities of situations, direct participation in and observation of the phenomenon of interest is necessary. This involved substantial amounts of time spent watching, listening to and learning from participants in the research setting. Consistent with my dual role as project evaluator-social researcher, and my goal to develop an insider's view of what was happening, I engaged in "the setting's central activities and events, assuming responsibilities that advance the group, but without fully committing [myself] to members' values and goals." This, Adler and Adler (1994: 379) referred to as "the active-member-researcher" role. Both direct and participant observational techniques were particularly useful because the results of this study depended specifically upon observing behaviors and meanings as they emerged in their natural setting.

There were also other advantages to using these techniques. Apart from being better able to understand the context within which participants operated, it afforded me access to personal knowledge and direct experiences as resources for understanding and interpreting data. It allowed me to be open, discovery oriented and inductive. I learned about things participants were unwilling to talk about in an interview and I moved

beyond the selective perceptions of others (Patton 1990). But I was also aware that my evaluator status, conventionally associated with someone who is an intrusive monitor, probably affected what participants were willing to share with me and how they acted in my presence. For example, participants frequently made funny comments like “Hope that’s not going in the report”? or “She’s gonna write that in the report, you know” when they saw me intensely taking notes.

My direct and participant observations involved recording field notes, which according to Bailey (1996: 80-81) consisted initially of mental notes, collected while interacting in the research setting. These were then turned into jotted notes, or brief reminder notes, which were used to jog my memory when I wrote more complete field notes. There are various ways to keep field notes. My field notes included a combination of jotted notes and verbatim quotes containing both descriptive and reflective notes about my experiences, feelings and reactions, portraits of participants, physical setting, verbal and nonverbal communications, particular events and activities, time and duration of observations. I then turned these into full accounts and stored them on my computer.

Documents, Archival Records and Physical Artifacts

Although suggestions for data-gathering usually promote the use of interviews and observation, Berg (2001: 227) noted that it is useful “to supplement this information with various documentary sources.” This is in keeping the ANT’s second methodological approach that researchers examine inscription devices. Thus, some of my data was obtained from project documents such as memos, letters, internet correspondence and websites, articles, books, grant proposals, charts, lesson plan drafts, agendas, written plans and statements of purpose. I also used archival records, like

departmental newsletters, project and departmental histories, and physical artifacts like photographs, drawings, sketches, and tape recordings of relevant project lectures.

Only the researcher, the advisor and committee members had access to the data. I used a tape recorder in both semi-structured and focus group interviews. Tapes were stored securely at the researcher's home, and were used to analyze data important to the report. With regard to confidentiality, workshop participants all signed informed consent forms allowing the release of information for the purpose of this study. In my discussions with participants, I also informed them that the extent of confidentiality was limited due to the size and visibility of the project, that is, the probability of identifying the scientists and project directors was greater than identifying high school teachers. Although a few participants (scientists) indicated that releasing their true identity was acceptable, for this study, I decided to connect all workshop participants to the data by using pseudonyms.

¹ An "actant," sometimes used instead of the "actor" is defined as any entity endowed with the ability to act, or "whoever/whatever is represented". Representations are the designation of someone or something as a spokesperson for an actant.

² There are four moments of translation in an actor-network: a) problematization – the process of defining the issue in such a way that other actors accept one's definition of the problem; they gradually come to accept one's knowledge claims or technology as an obligatory point of passage, i.e., a necessary means to solving their problem; b) interessement – the action of imposing and stabilizing the roles of other actors by attracting a second entity by coming between that entity and a third; c) enrolment – it is the device by which actors/entities are anchored to the network in interested roles; the definition and distribution of roles in the actor world; roles that are not fixed or pre-established and that may not necessarily be imposed; and d) mobilization – the achievement of desired representatives to act as spokespersons of other entities.

Chapter Four : ACTANTS

When we think of scientists, we often think of the lonely researcher, alone at his workbench or in the laboratory, separated from the rest of society. However, I have already shown that nanotechnology involves a host of interests – government officials, universities, companies, journals, etc. Everyone and everything that comprise the network is contributing to the nanotechnology work. This ensemble of interests, I refer to as “actants” – adopted from Latour as a neutral way to refer to both human and nonhuman actors. Actants perform the task of lengthening the network as they may be “enroled” or “allied” to give strength to a particular position. Actor-network theorists like Callon, Latour and Woolgar suggest that to understand how actors enlist other actors into their world, one must follow more than just one scientist, one teacher or even, one project director: one must focus on all actants.

This chapter provides a detailed account of the enrolment of the actants involved in the knowledge education production processes in the Geosciences Department at Virginia Tech. It addresses the following two research questions:

- What actors were enroled in the nanotechnology network?
- What actors’ interests and motivations influenced their enrolment in the network?

Although the entire project was funded for five years, I focused on the first two years – 2002 and 2003.

Because all actants are situated within social, political and/or economic contexts that provide the rationale for their roles, activities and behaviors, I first begin with the narrative of the situational context of how the outreach endeavor came to be and the institutional actors – the Fisher¹Group and the National Science Foundation (NSF) – who

brought the project into existence. Second, I provide descriptions of the human actors or participants of the 2002 and 2003 workshops. Third, I examine various interests and motivations that shaped the involvement of human actors in the NCDP. Finally, I describe and explain the role of nonhuman actors like labs, machines, tools, instruments and inscription devices such as narratives.

The Situational Context

Nestled in the southwest region of Virginia within the Valley and Ridge Province of the Appalachian Mountains, my journey with nanotechnology took place on the scenic two thousand, six hundred (2600) acre campus of Virginia Polytechnic Institute and State University (Virginia Tech) – a cosmopolitan university town in the rural setting of Blacksburg. Founded in 1872, this publicly supported land-grant university is well known for its picturesque beauty and its various recreational opportunities in golfing, hiking, canoeing, kayaking, fishing, caving and cycling. With approximately twenty six thousand (26,000) on-campus students in eight (8) major colleges and a full time instructional faculty of about one thousand, five hundred (1500), it has the largest full-time student population in Virginia, producing forty percent (40%) of the state's doctoral degrees.

Adhering to the motto – *Ut Prosim: "That I May Serve"* and guided by its three-fold mission of instruction, research and solving the problems of society through public service and outreach activities, the university is considered one of the major research institutions in the country. With an annual budget of approximately \$740 million and annual research expenditures of about \$170 million, Virginia Tech consistently ranks among the top 50 research universities in the United States (U.S). For instance,

Kiplinger Magazine ranked it the 16th best value in public higher education in the nation, and of all universities – public or private – *U.S. News & World Report* ranked it the 46th best value in the country. It also ranked its undergraduate program as the 26th best among national public universities and the university's engineering program in the nation's top 25. The NSF also ranked Virginia Tech 5th in the nation in agricultural research expenditures.

There are over one hundred (100) buildings on the campus which house several hundred research laboratories, as well as the Corporate Research Center (CRC), consisting of thirteen (13) additional buildings which contain several offices and laboratories for approximately seventy-five (75) private companies with over one thousand, three hundred (1300) employees. In a national study, CRC was cited for best practice of technology transfer. Virginia Tech also consistently ranks among the top fifteen (15) schools in the nation in number of patents received and among the top institutions in industry-supported research. Faculty and students are involved in more than three thousand, seven hundred (3,700) research projects in fields ranging from biotechnology to materials, from the environment and energy to food and health, and from transportation to computing information. It is one of the nation's leaders in developing and using new instructional technologies as well as one of the only two (2) universities in the country that offers a military-style leadership development program within a traditional academic life (<http://www.vt.edu/aboutvt/universityataglance.html>).

When school is in session, you can expect to find a lively, busy town with thousands of students, faculty and townsfolk bustling about. However, within the last week of any semester, it is not surprising to see droves of cars, minivans, sport utility

vehicles and U-haul trucks heading East on Route 460 toward Interstate 81 as thousands hurriedly evacuate the campus grounds for home (wherever that might be). In what seems to be “the blink of an eye,” the constant shuffle of feet, the chatter of gossip, the whizzing of cars going by with stereos blasting, the droning of faculty lectures as one passes in the hallways are gone. This is particularly noticeable during the three to four summer months where the scene on the campus is habitually described as “a graveyard.” It is this tranquil atmosphere during the summers of 2002 and 2003 that provides the setting for the nanotechnology workshops conducted by the Geosciences Department at Virginia Tech.

Located in a five story teaching and research center named Derring Hall, Virginia Tech’s Geosciences Department is ranked in the top twenty (20) Geosciences Departments in the U.S. In 1995, as ranked by the National Research Council, it was eighth (8th) in the U.S. among public institutions and the leading Department in the southeastern US, public or private. The Department has numerous computer and analytical laboratory facilities, and it operates a Worldwide Standard Seismograph Station and a regional telemetered network for earthquake monitoring. It also houses one of the three branch libraries on campus – the Geosciences Library, which includes a collection of 54,000 books, 16,500 geologic maps, 18,500 microfiche and 18,000 air photographs.

Situated in the center section on the second floor of Derring Hall, it houses the Geosciences Museum. Open from 8am to 4pm on Monday through Friday, the Museum is one of the Department’s most visible outreach programs aimed at introducing the public including elementary and high school students to over 11,000 mineralogical and

paleontological specimens. It is not surprising to find students and teachers lazily browsing through the extensive mineral collections, fossils and area mining history exhibits on display or to find a group of visiting elementary students huddling over glass cabinets of mineral collections as their guide enthusiastically explains the wonders of rock and mineral formations or simply a few students using the comfortable chairs and tables provided to sit around chatting, studying or reading a book.

The Department offers Bachelors, Masters, and Doctoral degree programs that cover a broad spectrum of geological and geophysical specialties and is supported by about twenty-three (23) permanent faculty members with approximately fifty-five (55) to sixty (60) graduate and eighty (80) undergraduate students. The faculty is considered to be “highly distinguished” in its research endeavors, bringing into the Department for the annual year 2001-2002 external funding totaling over \$6 million and industry support just a little over \$73,000 (<http://www.geol.vt.edu>). When I began this study, of the full time faculty members, there are only five (5) or roughly twenty-two percent (22%) females (all white). While the faculty is internationally diverse with professors from India, China, Turkey and so forth, there were no black, African American full time faculty members. This low representation in race and gender within the Department is consistent with the overall racial and gender composition in the sciences as a whole and in the Geosciences field.

The Fisher Group

For any scientific endeavor to survive, it must recruit and socialize members and create a sense of commitment to the research area. The literature on the social production of scientific knowledge (Badchuk, Bruce and George 1999; Crane 1972; Friedkin 1998;

Kuhn 1970) has shown that collaborations play an essential role in strengthening and expanding scientific networks. Moreover, Crane (1972: 56) found that research specialties were usually characterized by a core group of scientists who collaborated with each other. The highly productive scientists were able to have a substantial impact on the research areas in terms of setting the norms of research and maintaining cohesion of the area. They exerted their influence by surrounding themselves with a network of collaborators and students.

Within the Geosciences Department, several faculty members work in collaboration with graduate students on specialized areas of study. One such collaboration is the Fisher Group [headed by Steve Fisher] that has been exclusively involved for about fifteen (15) years in nanogeoscience. This is a new field within Geosciences that involves the study of materials and processes at the nanoscale in their role in geologic processes on the Earth and other planets. More precisely, members of the Fisher Group explore how interactions at the interface between nature and environment on and near the surface of the Earth influence or control how bacteria and minerals communicate. Their research focus on such issues as the purification or pollution of fresh water, the transport of metals away from mining sites, the development of soils and the distribution of nutrients within them and the adverse affects of mineral dust on humans.

Their work is particularly important in light of the troubling state of Geosciences. According to a report of a nanogeoscience workshop held at the Lawrence Berkeley Laboratory in California, June 2002, because of an overall declining interest in the sciences among U.S. students, there was a significant decline in the numbers and quality

of doctoral students in the Geosciences. Some Geosciences programs thrive because like the Fisher Group, they have switched focus to explore connections between Earth materials and environmental problems, thereby drawing students from other disciplines (Chemistry, Toxicology, Soil Science, Materials Science, Civil and Environmental Engineering). According to this report, “new emerging fields like nanogeoscience are an expression of this interdisciplinary vigor and herald an opportunity to reinvigorate Geosciences through research on modern problems” (National Science Foundation 2002: 22).

Thus, it was not surprising that when asked about his involvement in nanogeoscience, Steve stated to a reporter from the Virginia Tech *Arts and Sciences* newsletter that after talking to some colleagues, “we realized that microbe mineral interaction was a research field of the future” (Trulove 2001: 7). Other scientists in this Group also held similar views:

Well, everybody’s talking about it...it’s the new thing that’s coming around and everybody’s buzzing about nanoscience and not just. I mean I think previously engineering is where nanoscience and nanotechnology has been discussed. In the Geological Sciences, that’s, it’s extremely new and so...certainly, in Geology ... it gives us a new perspective on these things that happen at the micro scale.

The significance of the Fisher Group’s work to Geosciences goes beyond simply an exploration of a new frontier or the hype that surrounds it. According to James, a graduate student scientist:

At this moment there are no other research groups that are combining the biotechnology with the material science, the mineralogy and the aqueous chemistry in the manner in which we are doing it in our experiments. And I think these types of experiments are, the possibilities are so great because we can take many different kinds of enzymes, many different kinds of minerals, and we are really not limited in what we do, and the results that we get are unlike any other type of results that can be produced...

The Fisher Group was the first to use several nanoscience tools for earth science applications, including the scanning tunneling microscopy (STM) and the atomic force microscopy (AFM), which led to a number of discoveries dealing with nanoscale processes at mineral-fluid interfaces, an invention of a new mode of atomic microscopy called biological force microscopy (BFM) and over eighty-seven (87) publications in this field.

These discoveries, inventions and publications are important to nanotechnology as they make up part of the core of legitimacy and expansion of the network. According to Callon, Law and Rip (1986), they enable scientists to enrol supporters and to gain recognition and credit, which really represent “currency” that can in turn be used for investments through grants that are made available to them in the future. These granted resources allow them to continue work, therefore maintaining the integrity and growth of the network.

The National Science Foundation (NSF)

As I indicated earlier, the stereotype of the lone researcher in a private laboratory no longer applies. Hiskes and Hiskes (1986) show that since World War II, science has become a community activity driven by intense competition for federal grants and private-sector investment. Today, it is within and through such institutions that scientific networks are expanded and science is legitimized. This is particularly true for new research areas such as nanotechnology as sociologists like Merton have shown that without the presence of such infrastructures to keep research institutionalized, new specialties collapse. The availability of institutional funding is a critical component in scientific and technological advancements: “the receipt of reward is just one small

portion of a large cycle of credibility...which enables reinvestment and the further gain of credibility” (Latour 1979: 197).

The Fisher Group has been the recipient of several rewards to the tune of four and a half million dollars (\$4.5 million). It received one of the first ASPIRES (A Support Program for Innovation Research Strategies) grants from the Research Division at Virginia Tech and external funding from the U.S. Department of Energy, the Petroleum Research Fund of the American Chemical Society and the NSF. These funds went toward supporting on average about five to six (5-6) Ph. D. students and one or more post-docs that typically make up the research team.

This case study dealt with the role of the NSF as it was the institutional funding agency for the outreach workshops. The NSF is an independent U.S. government agency responsible for promoting science and engineering through programs that invest over \$3.3 billion per year in almost 20,000 research and education projects in science and engineering (<http://www.nanotech-now.com/government.htm>). Currently, it is the largest supporter of nanotechnology (Baard 2003). Also, the National Nanotechnology Initiative (NNI) is located inside the NSF and is now the third largest federal research project [just below the war on cancer and the Star Wars missile defense shield], with the largest federal subsidy of approximately \$221 million.

The NSF is currently making the largest investment among federal agencies in fostering the development of nanoscale science and engineering. Furthermore, the first “nano” program – on nanoparticles synthesis and processing – was initiated by the NSF in 1991, which continued to follow its commitment to interdisciplinary teams, synergistic centers and exploratory research in its program solicitation on Nanoscale Science and

Engineering (NSE) initiatives. For the fiscal year 2002, its investment priorities spanned a wide range of research and education activities in nanoscale science and technology, in order to develop and strengthen critical fields, to establish the physical and engineering infrastructure and to prepare the workforce (Roco 2002a).

The NSF's recognition [identified in its comprehensive publication, *Societal Implications of Nanoscience and Nanotechnology*] that "failure to invest in the necessary multidisciplinary research would delay or even prevent these benefits to the economy, to national security and to individual well-being" (National Science Foundation/U.S. Department of Commerce, 2002: 85) was a major impetus behind the extensive funding we are seeing today in nanotechnology work, also at Virginia Tech. For example, research proposals by nanoscience researchers in the Physics Department and a joint effort between Physics and the College of Engineering received Nanoscale Exploratory Research (NER) grants from the NSF to explore the nanoscale world.

As it pertains to this case study, NSF served four important functions. What we already know of scientific research indicate that it is expensive business. Thus, in its first role, the NSF allocated rewards by supplying the means for the Fisher Group's research: the money. In the Fall of 2000, the Group, consisting of three (3) faculty members, four (4) senior research staff and three (3) Ph. D. graduate students, jointly wrote and submitted a grant proposal entitled "Nanoscale Processes in the Environment: Nanobiogeochemistry of Microbe/Mineral Interactions" to the NSF's newest initiative, Nanoscale Science and Engineering (NSE) under the Nanoscale Interdisciplinary Research Teams (NIRT) Category. As noted in the proposal, the chief subject of this grant was to probe the unknown properties of single biomolecules, to recognize and

understand nanoscale processes that [would] lead to advances in bacterial transport modeling, contaminant migration and subsurface remediation strategies (Fisher 2000).

Consistent with its overall mission to promote the progress of science, along with its growing awareness of the possible significant effects of nanotechnology on the health, wealth and standard of living for people in this century, the NSF granted the \$1.1 million requested in the proposal for a five-year period beginning September 2001 and ending August 2005.

The NSF's enrolment was important to the expansion of the nanotechnology network, and scientists were well aware of the effect that this alignment had on their research endeavor:

...we can't do the research without the money. So, the money has got to be there... So, if, the science can't be done, it's very expensive science and it can't be done without big funding. So, if NSF or DOE, or DOD doesn't put the money in then it won't happen. I mean it might happen from, in the business end but in terms of the processes it really does take funding for that.

...the instruments for nanotechnology are expensive and it is exceptionally expensive to get started, to build these centers in new universities like we're doing at Virginia Tech where we don't always have all the instruments that we need. So money is a factor because in order to get these research ideas going, we either need to build a lab or we need money to travel and use other peoples' facilities.

Moreover, if Latour's hypothesis (1987: 168) is accurate that "budgets are a fair estimate of the amount of interest scientists have been able to secure for their work," based on the enormity of the grant, this might rightly suggest that the NSF was a very interested ally.

As a federal authority, the scope of funding reflected the NSF's interests in nanotechnology and it brought credibility to the Group's endeavor.

Thus, in its second function, the NSF was even more powerful as its authority was a mobilizing agent, driving further research agendas in the nanotechnology network

because as Stacy, a principal investigator and scientist commented, once the NSF approved something as worth pursuing, then everyone fell in line:

...NSF says here is a pile of money and so people sometimes think what can we do to get it? And so, funding, NSF funding definitely drives science. It drives the agenda for science, what gets funded in geology, any field...well just take for example, homeland security. Money will go into homeland security. So people say: ok how can I do that, what can I do, what can I do and they will come up with innovative thoughts and then, everybody will be on the homeland security bandwagon.

The NSF funding had the effect of lengthening the network consistent with Fujimura's scientific bandwagon concept where researchers flock to "hot" areas in science and technology. By allocating the money to the Fisher Group, the NSF was able to draw these scientists into the network of nanotechnology researchers and supporters already working in the field, thereby lengthening the size of the network.

According to LaFollette (1986: 57), most academic researchers cherish an idealized model of scientific freedom in which "a scientist sets his or her own research agenda, performs the research without fear of repercussion or criticism, and describes the work to anyone and everyone." However, when university research became dependent upon outside funding, it also opened the door to outside influence. As Crane (1972: 56) pointed out, "behind the seemingly impersonal structure of scientific knowledge, there is a vast impersonal network that screens new ideas, permitting some a wide audience and consigning many to oblivion." In this capacity, the NSF performed a third role: it acted as a regulatory or filtering mechanism, weeding out undesirable projects and rewarding those like the Fisher Group's that are seen as desirable.

One might even say that it functioned, in a Mertonian sense as a "gatekeeper," providing or denying access to opportunities through intermittent assessment of the performance of scientists in the Fisher Group. Through its peer review system, the NSF

acted as a “status judge” evaluating the quality of role performance for the Group (Merton and Zuckerman 1973: 460). Through its program solicitations, the NSF wielded regulatory power by not only defining the objectives of the Group’s research but also in maintaining social control over the scope, duration and direction of specific research endeavors. For example, solicitations stipulated that all proposals must contain a strong scientific research component, thereby inviting specific research agendas.

Within recent years, the NSF has become more involved in or intensified a fourth role, that is, the diffusion of scientific ideas into public arenas in an effort to develop “an informed public in nanoscience and technology” (Fisher 2000: 2). It embarked on a relatively new thrust, mandating that proposals must also have a strong educational or outreach component. Speculating on this new emphasis, Melissa, a scientist in the Fisher Group noted:

...they want to communicate this is science for the public and part of it maybe that I think the general public really doesn’t understand what scientists do on a day to day basis and I think that’s something the National Science Foundation is trying to work on, communicating what scientists do and how we do our research and how we end up getting the results that we get. So that people have a better understanding of not just how we did the research but the importance of the research that scientists do.

Charles, another scientist in the Group echoed a similar sentiment when he added:

...it’s hard to say, NSF is a political organization just like every other large governmental department or agency. They are highly dependent on the views of Congress and what Congress thinks. I think perhaps it’s a means of ensuring that the public knows what’s being done or least, at some level they understand what’s being done so that it assures that their, public perception is positive and therefore, funding will continue and it won’t be the sort of perception: well, there’s a bunch of people doing secret things over there and they won’t tell us what’s going on. You know are they doing good things or bad things and we don’t know. So, I think openness is a good policy from that standpoint.

Consequently, an important aspect of the NSF's outreach mission was to bring nanotechnology into the classroom, not just the colleges and universities but also K-12 programs. This new drive emanated from the NSF's recognition that

...future success in investigating systems at the nanoscale requires an increased focus on the role and scope of engineering education and, by extension, general science education. Allied with this sentiment are recommendations concerning the institutionalization of nanoscience and nanotechnology curricula in the K-12 education system and in the undergraduate curricula of colleges and universities... Within the next 5 to 10 years, it seems inevitable that suitably modified content material emerging from ongoing research in nanoscience and nanotechnology will eventually "filter down" and become incorporated in formal science instruction at the K-12 level. Clearly, science teachers at all levels need to be made aware of these developments and adequately prepared so that they are able to teach about these advances in a developmentally appropriate manner (Sweeney, Seal and Vaidyanathan 2003: 237).

Consistent with the NSF outreach mission, the Fisher Group proposed to develop a "sophisticated, yet affordable outreach plan... The heart of [the] plan involve[d] a series of secondary school teacher/teacher-in-training workshops at Virginia Tech... [They] propose[d] to have practicing and future teachers participate in exploring this frontier so that they will incorporate nanotechnology into their curriculum to teach not only their students, but also their colleagues" (Fisher 2000: 2, 14). By doing so, the Group initiated the first and only (at the time) series of school-university collaborative workshops attempting to take nanotechnology focusing explicitly on the Geosciences into high schools.

Human Actors

Collaboration between public schools and colleges of education has existed for a long time in the form of student teacher placement and a variety of in-service education ventures. However, only recently have proposals for reform and restructuring shed national attention on the idea of the two institutions working together on an ongoing and equal basis to solve problems and improve practice in both the schools and at the

university. Several influential reports – *A Nation Prepared: Teachers for the 21st Century* (Carnegie Forum 1986); *Tomorrow's Teachers: A Report for the Holmes Group* (Holmes Group 1986); and Goodlad's (1990) *Teachers for Our Nation's Schools* – all strongly recommended collaboration between the schools and colleges of education.

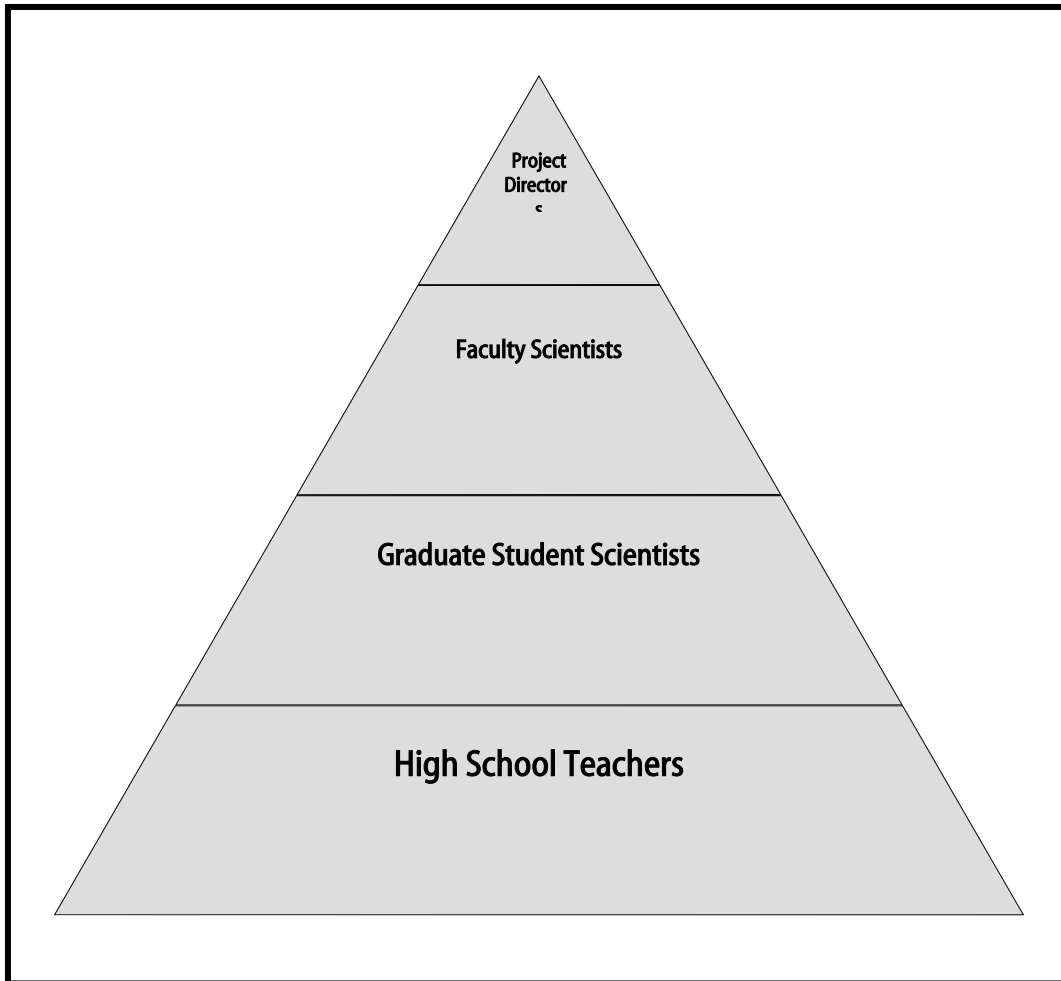
In the summers of 2002 and 2003, the Fisher Group held two collaborative workshops entitled the “Nanoscale Secondary Science and Math Curriculum Development Project” (NCDP) from June 17 to June 20, 2002 and from June 16 to June 19, 2003. The goals of the first and second workshop were to engage high school teachers from southwestern Virginia in learning activities about microbe-mineral interactions at the nanoscale and to begin the task of producing materials and resources in the form of lesson plans that could fit into secondary science and math curriculum.

These workshops were intended to create a “true collaboration” or as Goodlad (1991-1992) classified a “symbiotic relationship” between university faculty and high school teachers. Nevertheless, in any project, no matter how collaborative the effort, there exists an organizational structure. In identifying nine conditions necessary for effective collaboration – time, benefits, support from the administration, core group, collegiality, mission, process models, flexibility and structure, McGowan (1990) highlighted that the group needs to set up “an operational structure” that should provide a process for decision making.

In the NCDP, although workshop participants attempted to avoid setting up a formal organizational structure, among human actors, there existed an operational structure based on actors' level of academic and scientific expertise. From my

observations, I identified four groups of human actors as diagrammed in Figure 4.1 below ranked in order of hierarchy.

Figure 4.1: Organizational Structure of Human Actors



In the following section, I address part of the following research question:

- What actors were enrolled in the network?

I provide some descriptions of the human actors involved in the NCDP – project directors, faculty scientists, graduate student scientists and high school teachers.

Project Directors

During the timeline of this case study (2002-2003), the project had two directors – Stacy, a white female Geosciences faculty member and Gary, a white male educator from

the Department of Teaching and Learning. They were involved in the managing the NCDP and facilitating curriculum development processes.

Stacy

In the Fisher proposal, Stacy was identified as an “expert” in Geosciences education, and thus, she was chosen by Steve to oversee all outreach operations. She was an Associate Professor of Geology who began her studies some thirty-five (35) years ago as an undergraduate student and later, received her Masters in Mineralogy and her Ph.D. in Geology. She had been at Virginia Tech since 1981, had taught many undergraduate level courses in Physical Geology and taught in an informal situation through the Museum.

Although she was an Associate Professor, having worked extensively on and published research in mineralogy, her specific interest in the Department was finding ways to educate elementary, middle and high school students about Geosciences through collaborations between higher education and K-12; an interest that was driven by her philosophy that “science affects society and society affects science”:

...I was a scientist because I was thrilled with knowledge, you know the knowing of it. And to be a scientist was to know how things work, to get, to understand the grandeur of this, complexity, or the mysteries of the earth or minerals or whatever it is. So, I did it for the pursuit of knowledge and I think that's fine. I think that's one role of science. But I don't think scientists should keep it to themselves and sit in the ivory tower, I think science needs to have a responsibility to share that, to inspire young people, to educate the public and to do good. I think you know we need, scientists has done a lot of bad, you know we get, for instance all the corn crops and the seed crops that we're exporting to other countries that we're losing the diversity of our seed population, we're losing local economies, we're losing so much because of science. It's that back to what I said earlier if we can do it, we should do it, I don't think that's true...

In pursuing these academic interests, she collaborated with other physical and natural science, mathematics and education departments in community colleges, other universities and public school systems throughout Virginia.

She served as the curator of the mineral collection in the Department's Geosciences Museum and as the director of the Natural History Museum where she was involved in a number of funded and non-funded outreach projects for teacher development including workshops and programs like Kids for Teachers. She worked with various museums across the nation in both mineralogy and natural history on public education. She was a project director and principal investigator on many collaborative projects including VQuest [an interdisciplinary Math and Science project with teachers and the scientific community], Science and Gender Equity, and a Howard Hughes funded project. In addition to her many outreach endeavors, she was the recipient of awards like the Outstanding Educational Display, Tuscon Gem and Mineral Show (2002-2003) and best paper for the journal *Rocks and Minerals*, presented by Friends of Mineralogy (1996). For two (2) consecutive years, she was the President of the National Friends of Mineralogy (2002-2003 and 2000-2001).

Gary

Gary was a white male professor from the Department of Teaching and Learning who started out in the role of the project's external assessor – a role which changed to the curriculum expert before the first workshop began. As a science educator, he taught in secondary and middle school for eleven and a half years (11½) and taught in higher education for fifteen years (15); fourteen (14) of which he spent at Virginia Tech. He had an undergraduate degree in Zoology, a Masters in Science Teaching and a Ph.D. in Curriculum and Instruction with a specialty in science education.

Throughout his career, he worked on several collaborative projects involving curriculum development. One of the most recent was a project on Earth Systems Science

in which he worked with NASA scientists to develop curriculum and another was on Geological and Biological Change or Evolution which involved scientists from different fields working with teachers. In his capacity as curriculum project director in the NCDP, he helped Stacy in the planning process, designing recruitment packages, formulating pre-workshop interview questions, interviewing scientists and developing workshop agenda drafts.

Faculty Scientists

In the first year, two (2) faculty members: Melissa, a white female and Charles, a white male, from the Fisher Group were involved in presenting the scientific content related to nanotechnology and its applications to high school teachers. Although Melissa was still very much involved in the second year, due to other research commitments, Charles' involvement decreased significantly. Prior to the NCDP, the collaboration experiences of faculty members were mainly scientific research endeavors, that is, they had no experience working closely with high school teachers or other "non-scientific" publics.

Melissa

At the time of the first workshop, Melissa was a relatively new Assistant Professor to the Geosciences Department. She had been at Virginia Tech for three (3) years teaching lower-level undergraduate classes and some graduate classes. In her academic career, she started out as a History major but quickly realized that she was more interested in environmental science and switched to Geosciences. Describing her professional life, she jokingly claimed that unlike many of her colleagues, she "stayed on the straight and narrow path" earning her Bachelors, Masters and Ph.D. in Geological

Sciences. After graduating from college, she worked as a hydrogeologist for an environmental consulting firm in Boston, which influenced her research interests in ground water. One of her specific research areas was contaminant bioremediation, which related to improving the understanding of geochemical and microbiological processes affecting subsurface contaminant transport.

Typically, hydrogeologists work at a larger scale than the nanoscale, but Melissa became interested in using nanotechnology for Earth Sciences applications because of its ability to help her understand how bacteria is transported in groundwater:

...since my goal is really to understand how contaminates are transported better, if we can quantify, and my goal is really to quantify the processes. So we know things happen, we know microbes can contaminate, I mean can degrade contaminates and we know that bacteria can get transported, but how do we quantify that? And once we quantify that, we can use a predictive type model, and once we design a model, we can better manage a contaminated site. So if we know where things are going, we know the direction of contamination, we can better design remediation systems or decide that nothing needs to be done... So it's, in terms of managing contaminated sites and designing contaminate remediation, this is where my research would be important.

Her interest in nanotechnology did not emanate from a purely academic acculturation. It began with her own personal experience in her hometown where for years, the drinking water smelled like pool water. Through her research on the contaminant fate and transport of arsenic and organoarsenic compounds, she wanted to make some contribution to fixing the huge contamination problem for water supply in the U.S. and all over the world – a problem which seemed to be “getting worse and worse as population increases and septic tanks are not designed properly [making] it very easy for bacteria to get transported.” Her interests rested on the practical usefulness of her research in influencing policy to find cost effective ways to clean up contaminates.

Charles

According to Drexler (1986), a key area in the multidisciplinary field of nanotechnology involves molecular engineering. In the Fisher Group, Charles – a postdoc Research Assistant Professor with a Ph.D. in Environmental Engineering – filled this position. He became involved in the Group after having taken a graduate course with Steve. During his Ph.D. work on treatment processes for drinking water, he concluded that the culture of environmental engineering was “highly trial and error oriented” and became more interested in trying to understand the fundamental processes that were responsible for physical behaviors in drinking water treatment. As a graduate student, he also taught undergraduate level classes in Material Science laboratories.

Although his current job description at Virginia Tech did not afford much time for teaching whole individual classes, in the past, he taught Environmental Engineering classes at the undergraduate level for several years and lectured in a number of classes at the graduate level. In addition, while serving on active duty in the Navy for six or seven (6/7) years and then in the reserves for about seven (7) years, he taught undergraduate level Science and Engineering classes including subjects like thermodynamics, fluid mechanics, heat transfer and mechanical theory.

As a research faculty member, he spent the bulk of his time pursuing research interests that involved biogeochemistry of microbe-mineral and microbe-cell interactions with applications in environmental engineering and health sciences:

...One of the aspects of what I'm doing is looking at what processes and how can we understand bacteria adhering or sticking to mineral surfaces and there's all kinds of practical applications where that's tremendously important, everything from dental carries, tooth decay. There's all kinds of theories about pathogenicity of bacteria and essentially bacteria that are pathogenetic often have some kind of sticking mode or they can recognize a particular type of tissue or cell, corrosion of steel pipes that distribute water. So, they're, everything from

the classical you know put a steel pipe in the ground and distribute your water to understanding biomedical problems are related to understanding how bacteria interact with surfaces often mineral surfaces. So, hopefully, my work will lead to some better understanding of that process and therefore, ultimately processes or new techniques by which you can minimize things like tooth decay or corrosion of a pipe or clogging of a heat exchanger in a power plant or all kinds of things. So, I guess I ultimately want to look at things that will lead to practical solutions to problems as much as just gaining the knowledge for the knowledge itself.

Graduate Student Scientists

Over the course of the two (2) years, four (4) graduate students – two (2) white males, Terrence and James, one (1) white female, Rachel and one (1) East Indian male, Sam – participated in the workshop. At any given time in the life of the NCDP, there were three (3) graduate students at each workshop. In the first year, Terrence, James and Rachel were heavily involved in the planning and dissemination of nanotechnology information to high school teachers, and in the second year, James, Rachel and Sam worked with high school teachers to produce drafts of lesson plans for curriculum development. Most graduate students had been working for at least two (2) years with faculty scientists and were considered highly competent. Like faculty scientists, before the NCDP, graduate students had very little experience with outreach collaborations that enabled them to work with “non-scientific” publics.

Terrence

Among the graduate students, there was a distinct hierarchy. From the beginning, James and Rachel kept referring to Terrence as the “lead.” Later, I found out that they did so because he had the most lab experience and was heavily involved in the writing of the NSF grant proposal:

The other students who are involved, one came in a semester after me and then the other came in a year after me so it was just kind of tenure seniority type of thing where I was there and I was involved in the proposal writing process so I kinda got in on the ground level and I guess knew the most about it from the start.

At the start of the first workshop, Terrence held a Bachelors degree in Geological Sciences from the University of Texas at Austin, a Masters degree in Geochemistry from the University of Montana – Missoula, and he was in his last year of doctoral work in Geochemistry/Biogeochemistry. While working on his Ph.D., he became interested in nanotechnology because he “found [himself] striving to kind of dial down”:

I know that what drew me to nanoscience was just the, you know to me it's another world, it's exploring a different world. I mean people talk about exploring space or exploring the ocean and these are all vast frontiers that we know relatively little about. I look at the nanoworld in that way, I really do. The thought of making measurements between single molecules and atoms interacting and then you know maybe going up slightly in scale with manipulating molecules into groups and making them work for you and turning them into machines, I think that's just about as good as it gets.

In keeping with the “endless frontier” rhetorical themes, Terrence felt that this field not only provided him with answers to many questions not formerly explored but it was also “intellectually satisfying.” Thus, under the tutelage of Steve, his research interests focused on measuring forces between a biomolecule and a mineral surface. Like the faculty scientists, he wanted to understand how the interactions between a biomolecule and a metal affect water quality and supply in order to model and predict the risks associated with such contaminates. He also saw the practical implications of his research as important to environmental studies in the area of contaminant fate and transport; an issue of public health and safety.

James

As part of the Fisher Group, James helped write the NSF proposal. He was a second year Ph.D. student with an undergraduate degree in Geology from Michigan State University, where his strong research involvement led to his interests in nanotechnology. He wanted “to really get down deep and see what's going on.” When he arrived at

Virginia Tech, he was extremely pleased that Steve, instead of looking at a process as a natural occurrence, challenged students to focus on why or what caused the process to occur in the way that it did:

...Our advisor has a style that he wants you to choose everything you do. He wants you to find something that you really love to work on...So, you know lots of environmental problems you can see great things happening and you get useful information but in order to really be predictive and say I'm going to understand what's happening over there and not just where I am now, you know you have to look at those at the molecular level, what types of transformations are occurring and that's what attracted me.

His familiarity with the nanotechnology literature and being able to see what nanotechnology could offer to the field of Geosciences “really turned [him] on,” and so he joined the research team. At Virginia Tech, he participated in intensive training in Biological Sciences such as labs on DNA extraction, sequencing, mutation and bacterial DNA generation. As a result, he developed an extensive background in Biotechnology. Seeking to combine both his Geosciences and Biotechnology expertise with his current interests in nanotechnology, James's research focused on geochemical interactions at mineral surfaces, nanoparticles' reactivity in the environment and what role they had in processes involving transformations in the earth. Like other scientists in the Group, he was trying to understand and predict how biochemical disturbances affect the environment, particularly all types of groundwater – surface, sediment and seawater.

Rachel

Like James, Rachel was in the second year of her Ph.D. program. Growing up in a very rural region on the eastern shore of New Brunswick, Canada, she became interested in Geosciences because of her personal experience with bacterial contamination of the drinking water systems. She came from a very rocky province in Canada that was inhabited for approximately five hundred (500) years by communities

that typically numbered around two hundred (200) people dispersed about two hundred (200) kilometers from each other. The inhabitants regularly built and used old contaminated well systems because they could not afford to install public water treatment plants, especially in the rural areas where “there just aren't enough people to have treatment plants at all.” To deal with contamination problems, Rachel revealed that they spent at least one to two (1-2) months of the year using boiled water.

Growing up having to use boiled water most of the time, not being able to drink the water and being from an area that was so poor that they did not have water treatment facilities had a huge impact on her life and academic career:

...you start thinking how can we fix this problem without a lot of money and so, trying to apply this nanoscience and academic research that does always have real world applications but taking that and applying that to a real world application was what I wanted to do...we need to be able to design some sort of filter or some sort of geologic control that stops that ground water pollution.

Her desire to find ways to potentially solve the problem led her to St. Francis University in Nova Scotia where she completed her Honors degree in Geology and Chemistry. Later, she went to the University of Nevada, Las Vegas where she did her Masters in Geology and Economic Geology. There, she worked in the world's second most abundant gold mine looking at alterations associated with gold deposition. Feeling a bit guilty for working in a gold mine and “taking away from the land” led to an even deeper resolve “to do something that was a little bit more environmentally sound.”

She came to Virginia Tech to study with the Fisher Group. On her first visit to the campus, she saw their research on bacteria interfacial forces with mineral surfaces and realized that this was what she wanted to do. At the time of the workshop, her specific research interest focused on being able to predict the actual path of the bacteria to better control contaminants that moved through the groundwater systems. Reflecting

on her personal influences, she stated that “I’m looking at it as an environmental public health person and I want to know if we can use these nanotechnologies to get rid of the bacteria in your drinking water. I want to use this on specific environmental contaminate problems.”

Sam

In the Spring of 2003, Terrence graduated and Sam – a first year Ph.D. international student – joined the NCDP during the second workshop. Before coming to Virginia Tech, he was trained as a Geologist, receiving his Bachelors degree from Presidency College, Calcutta, India. While working on his Masters in Applied Geology, his interest in the oil industry led him to pursue another Masters in Engineering at the Indian Institute of Technology (IIT); one of seven (7) institutes of technology created in India as a center of excellence for higher training, research and development in science, engineering and technology. Comparing his experience there to Virginia Tech, he noted that it “took a lot of things away from me. Cause it grilled me so hard that I didn’t have a life. Ah, study, study, study. [Here, at Virginia Tech], the coursework is really hard but then you have a life.”

It was while working on his Masters thesis in acid mine drainage that he was introduced to “the biological side of things.” In India, there was no institute that focused specifically on Biogeochemistry or Biomineralization or the overlaps between the biological field and the Geosciences. Much of what was taught to him was a “Puritan Geology” as he put it; something from which he wanted to break. Later, while surfing the web, he came across information about the Mine Environment Neutral Drainage (MEND) program in Canada – a cooperative research organization sponsored, financed

and administered by a voluntary consortium of the mining industry, the Government of Canada and eight provincial governments. He discovered that MEND was implemented to develop and apply new technologies to prevent and control acidic drainage and began to realize the scope and potential for research in that area.

Looking into the Environmental Protection Agency (EPA) websites and guidelines for drainage mines, he began to feel a “strong pull” toward environmental remediation and Geomicrobiology. His interests in these areas led him to apply to the Geosciences Department at Virginia Tech to work under the guidance of Steve. Although he did not have a concrete research proposal when I interviewed him, his interests centered on a number of topics: environmental remediation techniques, nanoscale reactivity, kinetic reaction and reduction rates of different minerals like manganese and of specific oxidation states. These were very important to him because in part, he realized that in nanotechnology, “a lot of data [was] missing” and that his research could help fill this gap.

The scope of nanotechnology with the potential for him to “do whatever [he] liked” also directed his research interests. He saw nanotechnology as “one of the most exciting areas of uncharted territory in terms of research,” with “no stagnation”:

It’s not like the classical geological sciences where everything has been done and redone, and done and done again. So...it’s high time that I find something during my Ph.D. that will ultimately have a bigger scope for me to work on when I enter research and academics. So, nanoscience, biochemistry, these are really two nice fields that can be developed in the next 50 years. So, why not I go into that?

His interests also developed from his personal experiences with acid mine drainage and water supply in India where environmental regulations were virtually non-existent:

People don’t know about anything else other than arsenic pollution or uranium pollution. They are not concerned about adding pollution, manganese pollution. See, clean drinking water is a problem over there. Now, nobody’s cares. I mean

the common man does, the man who lives in the village, he doesn't care about whether he's having iron more than 5ppms than the standard allowed limit in his stomach. So, what led me into acid mine drainage was this fact that in India, people are so relaxed about the fact that's so much stuff coming into the waters. I mean the river I worked in, that's just near the mine site, it had no aquatic life. Can you imagine that? All the fish was dead, everything was dead. How can that be?

Of equal importance to Sam was the ability to do his research unfettered by government restrictions. For instance, he revealed that when he worked in a government controlled mine, he was told that he could not do anything related to environmental geology but he playfully admitted that he “tricked them”:

...I used to work in the second half and the first half I used to go over there and like talk about geology and stuff like that, hard core mine geology. Second half after lunch, I used to come out, take my bottles, go and take samples. So, if they knew that, they would have just thrown me out at that point. So, those are the things that actually pushed me into this. Because I saw this, it's like Indiana Jones, yes, yes. So, yeah, independence and moreover that this field is totally new in India, totally new in India, at least in South East Asia, this is totally new... See, my point is that I want to continue in research and science so anyplace that gives me like tools and my freedom of thought, speech, I'll go there. It may be Africa, it may be Australia, Antarctica I don't care. I need, see I've trained my brain, so I need my brains worked. And I also need my freedom, my space.

High School Teachers

In April 2002, about a month before the acceptance deadline, Stacy and Gary drafted and sent application letters and packages to principals and administrators in nearby high schools, notifying them of the NCDP, its goals, requirements, eligibility criteria and compensation provisions. In the package, they requested that teachers “participate for 3 years in a summer institute which involve[d] learning about nanoscience or technology from researchers, participating in research on a limited to extended amount, and developing and disseminating curriculum using nanoscience or technology.” High school teachers eligible to participate included Biology, Chemistry, Earth Sciences, Physics and Mathematics teachers in Virginia's Region VI who had two

years minimum teaching experience and received recommendations from the school Principal.

Among these formal credentials, the criteria noted that they must have a background in the discipline content area, the ability to commute to Virginia Tech, experience in curriculum development and the “ability to carry through” on a project. In this application process, teachers were also asked to address the following: what experiences would they bring to enhance the project and describe their approach to teaching science. See Appendix B for a copy of application form. Initially, the Fisher proposal stipulated that ten (10) teachers would be recruited for the workshops. However, citing lack of financial resources, directors decided to cut that figure in half. Of the ten (10) teachers who applied, they initially selected five (5) teachers – three (3) females and two (2) males – to participate because of “their interests in curriculum development” and “their expertise from the classroom.” In the second year 2003, another female teacher was added to the NCDP.

Before the workshops, high school teachers had a very limited knowledge of nanotechnology. For some, the extent of their knowledge was simply that they heard the word before and knew it dealt with things on the molecular level but they had no idea “what it was being used for, how society had used it or wanted to use it.” Others had some prior experience with nanotechnology either through their personal reading of scientific journals and magazines or just from being in the sciences. As far as “a firsthand knowledge of what they really did,” they did not know. Despite their limited knowledge, the enrolment of teachers in the NCDP was voluntary. As Rachel pointed out

one day during the first workshop, “these teachers want[ed] to be here, they all applied to be here.”

Kate

Kate was a white female who described herself as a “people person,” which I found to be accurate based on my observations of her friendly and sociable disposition. She taught four major sciences - astronomy, oceanography, meteorology, geology – that fell under the umbrella of Earth Sciences at a high school about sixteen (16) miles from Virginia Tech. She had a Bachelors degree in Geology from the Virginia Tech’s Geosciences Department. In her nineteen (19) years of teaching, she was involved in numerous committees and projects like the NCDP. For example, she spent three (3) summers working on a committee of fifteen (15) teachers to create an Applied Physics text, and she was involved with the “groundbreaking” task of writing criteria for the Department of Education Standards of Learning (SOL) in Earth Sciences.

Her experience working on curriculum development committees, the fact that she received many awards in the area of Earth Sciences and that she had prior experience in publishing CDs and teachers’ guides were some factors that made her attractive to the project directors. She entered the project with several expectations, many of which reflected that she was very applications/practice oriented in her approach to science. From the onset, she wanted “to see data and methods. I would like to incorporate this project into SOL tests. I want a variety of information and hands on experience.” She was particularly interested in “seeing” what the scientists produced, the data, how they collected data and how it was being used before she “dipped in the water.”

Megan

Megan was also a white female teacher from a nearby school about twenty-four (24) miles away from Virginia Tech. She had a friendly and warm disposition. She taught Physics for seventeen (17) years and had an undergraduate degree in Geophysics from the Geosciences Department at Virginia Tech. Prior to her current teaching appointment, she also worked at the same high school as Kate and so, they knew each other very well prior to the project. Like Kate, she too stressed the need for hands-on experience with nanotechnology: “I want to get hands on experience...I want my students to get hands on experience as well...I would like to use this as a real-life example showing students that the information they are learning may come in useful.”

Anna

Anna was also a white female who, for five (5) years, taught Mathematics at a high school in Giles County, some twenty-eight (28) miles away from Virginia Tech. She had a Bachelors degree in Mathematics from Concord College. Although the Fisher Group proposed to include all science and math areas in the NCDP, from the onset, the expected contribution of Mathematics to curriculum development was unclear. Even Anna was hard pressed to see how she might fit into the project. However, one of the project directors pointed out that “Math is the language of science” and so, fitting it into the curriculum should not pose a problem.

Daniel

When asked about his ethnicity, although he looked Caucasian, Daniel indicated that he was not sure. His disposition may be described as “calm, cool and collected” as he often appeared in khaki shorts and a loose fitting shirt or T-shirt. He taught for seven

(7) years at a high school about thirty (30) miles away from Virginia Tech in the Roanoke area. Despite the distance, project directors selected him partly because he was very self-motivated: a few years after obtaining his undergraduate degree in Biology, he returned to get his Physics certification. In addition, although high school teachers were required to maintain their professional portfolios, which entail doing a certain amount of workshops, publications and testing, Daniel had already fulfilled his requirements and was not going to be required to do “anything for another three years.” Project directors selected him because of his interests in learning about nanotechnology. Though, he began the project with few expectations and with some apprehension, not really sure of what he wanted from the project and not clear on what he should be doing, he expressed that he was “really happy” that he got accepted.

Anthony

Anthony was the only African American teacher in the workshops. From the start, he seemed to be a very easygoing person. Previously, he taught chemistry at a nearby high school about six (6) miles away from Virginia Tech, but recently began his graduate experience full time in the Department of Teaching and Learning at Virginia Tech working on his Ph.D. in science education. Initially, he began working on a Ph.D. in the Chemistry Department and completed most of the coursework before deciding to switch. Anthony planned on graduating in December 2004. Having taken up the science education baton, he also saw it as an opportunity “to get back to the technical side.” His status as a teacher-in-training and his past experience as a chemistry teacher whose students had received very high SOL scores were some of the reasons project directors saw him as an asset to the team.

Jenna

Jenna was a white female Chemistry teacher from a nearby high school about two (2) miles from Virginia Tech, who joined the project in its second year. Although she was approached by the outreach director in 2002 and was very interested in attending the workshop, she was unable to do so because she already had a summer job. However, when she learnt that the project was still being run in the summer of 2003, she asked Stacy if she could be on the team. When she joined, she was in her thirtieth (30th) year of teaching. She had a Bachelors degree in Math with a minor in Chemistry and a Masters degree in Counseling and Guidance with a minor in Math. At the time, she was also pursuing a Ph.D. in Curriculum and Instruction in Science at Virginia Tech. To her, it was quite a challenge coming midstream into the project but having worked with Stacy on other projects, Jenna felt motivated.

Interests and Motivations

Latour points out that in order to enrol human allies one has to not only make them interested but one must also create an alignment of the other actors' interests with their own interests. Thus, Latour presumes that all actors have interests, that is, motivations and influences that make actors want to join a network. However, what he does not explain is exactly what those interests are, nor does he show the array of motivations for actors' enrolment. This, Amsterdamska (1990: 502) refers to as an "indifference to the means and methods of enrollment."

In this section I look at Latour's notion of interests more closely to address the following research question:

- What actors' interests and motivations influenced their enrolment in the network?

Understanding actors' interests and motivations is important to network building and growth because they provide the basis for human actors' enrolment and link to the nanotechnology network.

In this case study, I found that human actors had several personal and professional interests and motivations – expertise, rhetoric, awareness, teaching experiences, personal history, academic and career opportunities, prior affiliations, monetary gain and requirement – that influenced their enrolment in the nanotechnology network. These interests and motivations provided the reasons for their involvement in the NCDP and ultimately, led to the growth of the nanotechnology network.

Expertise

The tasks of constructing and expanding require not only the alignment of interests but also the alignment of expertise. This is particularly important for the multi-disciplinary field of nanotechnology. In this workshop, although nanotechnology was not Stacy's research field, she became involved in the NCDP when the Fisher Group needed someone to write the outreach aspect of the grant proposal. Her outreach expertise in the Geosciences Department influenced her enrolment. In a pre-workshop interview, she recalled how she became involved in the NCDP when Steve Fisher, on leave in Australia, contacted her saying:

...we need an education component of this thing we're putting in, would you write it? And I said well let me think about it. So, I talked to him and to find out what it is and one of the things in my personal agenda, or my professional agenda is to get more faculty involved in outreach working with K through 12...the good of working with teachers, it's a thing we should be doing.

Similarly, Gary's enrolment as curriculum project director was motivated by his extensive professional background and expertise in science education and curriculum development. He confided that although he started out in the role of external assessor,

“the more [the project directors] talked...the more [he] thought [his] talents would be better used to curriculum development aspect of the project.” Although the teachers voluntarily applied to join the NCDP, “their interests in curriculum development” and “their expertise from the classroom” were cited by Gary as primary factors influencing project directors’ decision to enrol them in the NCDP.

Rhetoric

I have already shown elsewhere (Chapter Two) that rhetoric can bring about the alignment of actors’ interests and influence others to enrol in a scientific network such as nanotechnology. In this case study, this was observed among the scientists and project directors. They all bought into rhetorical themes – “endless frontier,” “social utility” and “inevitability of progress” – found in nanotechnology articles, magazines and policy documents. These themes seemed to motivate them to join the NCDP.

For example, because the scale was new, the instruments were new and the research was new, they felt that nanotechnology was “cutting edge” science. In the words of Gary, it was “phenomenally cutting edge”:

...it’s like exploring a new world, we’re able to see into a world in a way that we’ve never seen before...I mean when you get to a new front, it’s a frontier of size and it’s a new world. You can explore in different ways and the possibilities, it’s almost like being a pilgrim or adventurer, explorer.

This “endless frontier” was one of the rhetorical themes that motivated them to enrol in the outreach endeavor of telling others about “cutting edge” science and later, it was used to influence the enrolment of high school teachers.

Another rhetorical theme which influenced actors’ enrolment was the “social utility” principle: nanotechnology would have significant positive impacts on society. Scientists’ belief in the potential benefits of nanotechnology and their frequent use of

statements like the ones listed below influenced their decisions to enrol in the NCDP, as well as enrol high school teachers:

I think it has exceptional benefits in the medical industry, in computer software industries and in general research in many interdisciplinary sciences. So, I think it's going to have a huge influence on the general public through those you know software computers and hospitals and medical industries.

It's a whole new way of building things. We can take atoms and build things out of atoms and so in that sense, you know whatever we can do now, we can do it better because we can design molecules that are stronger than steel and gears that work better. You know just everything that we think of in a practical sense what if we can do it on a smaller scale where we design it to maximize the properties of those atoms exactly how they would most benefit us.

Buying into the traditional progress themes, scientists and project directors also saw nanotechnology's impact as inevitable as epitomized in Charles' comment below:

It's something, yeah it's gonna have a big impact and it's gonna be around for a long time. It's not gonna be just a fad that we go through it for four or five years and then we move on to the next thing. It's here to stay...ultimately I think it's gonna impact society at pretty much all levels. At some point in the future, it's probably not gonna be next year that it does that, but in five, ten, twenty years, we're going to be doing a lot of things fundamentally differently. Maybe we're not going to be making steel anymore like we used to make steel or we have made steel for a hundred and fifty years or. So, in every aspect, at every level, I think it's gonna impact society...The genie is out of the bottle and you're not going to stop it now.

This “inevitability of progress” rhetoric motivated project directors and scientists to undertake the responsibility of expanding the nanotechnology network by “making [others] more knowledgeable” so that they could “make wise and informed decisions.”

Because they saw these impacts as inevitable, that is, lack of human agency to change its course, they exercised their agency by acting to help high school teachers and ultimately high school students understand the changing nature of the world that nanotechnology would inevitably usher in.

How important were these rhetorical themes as motivating factors in the enrolment of others? The following comments indicate that such rhetoric influenced high

school teachers' enrolment in the NCDP. Anthony noted that his motivation for joining the NCDP was that nanotechnology was "something new and exciting that I'd never done before". Julie joined because she felt that "nano, the nano effort is just, is becoming so important and I needed to learn about it, and I knew that I would learn about it if I was involved in the project." Kate also described her motivations in a similar way: "I didn't know much about nanotechnology at the time, but I thought well this is an upcoming cutting edge type of project so it was something that I would like to work on."

Furthermore, post interviews conducted with some teachers at the end of the first workshop revealed that many shared project directors' and scientists' beliefs that nanotechnology was not only "cutting edge", but would positively impact their lives and that nanotechnology's reach was inevitable. These beliefs are epitomized in the following comments from Megan and Kate:

I think it will impact the students' lives in that it's gonna show up in their lives more and more...the benefits here are that when they see the term nano, they won't say: oh, yeah that's that stuff I don't understand. You know, hopefully, they'll say oh yeah, nano, I know about that, remember this and this and they have something to link any new information to, some way to sense of it.

I think it's very cutting edge science. At the same time, I'm excited about it but at the same time, I'm scared about it because it's one of those things that opens up a lot of ethical issues and moral issues for me. And, then, but yet I'm a scientist and you know I'm excited about the sciences being done. So, it's, it's an exciting time I think to be involved in nanotechnology and what's available and also, too it makes me want to read more about the literature and that type of thing and look things up.

These rhetorical themes continued to influence high school teachers' decisions to remain enrolled in the NCDP.

Awareness

For project directors and scientists, the idea of making others awareness of nanotechnology by teaching high school teachers who would in turn teach high school

students was a major motivating factor that influenced their enrolment. For Stacy, this interest was also driven by her active involvement in collaborative outreach endeavors for about twenty-two (22) years. She was so passionate about outreach that in the 2002 pre-workshop interview, she referred this aspect of her work as the “legacy” she wanted to leave behind in the Geosciences Department. Her personal interest in building avenues for faculty and graduate students to love outreach was one factor in influencing her enrolment as the project director. She was also “really excited” to be a part of the NCDP because she felt that it provided a “nice opportunity” to bring “cutting edge science...cool science” to high school teachers and students.

Although her knowledge of nanotechnology and the work of the Fisher Group were limited, she strongly felt that because science did not exist within a vacuum, outreach was important for “the new generation” as an empowering tool to “help people understand science” to be able to make informed decisions:

...I am not doing research but I have sort of conceived and planning and now directing the implementation of the curriculum development and that part is the transferring of the knowledge of what the scientists know to the public school setting...to help facilitate [the scientists] and the graduate students in doing outreach so that they learn from teachers. It’s not a one way street, scientists also think well, we’re brain dump on the teachers and then they’ll be better teachers. But to understand the culture of the public schools, to understand how to work with teachers, to feel the joy of the rewards of working with the public or the non-scientific people... it’s partly my role is to help get the [graduate students] involved so that when they grow up and go have jobs then it’ll be an easier task for the next generation...

As science education was Gary’s forte, it wasn’t too difficult to understand what motivated him to become involved in the NCDP:

...one of the things that I do value is the connection between education and science education in the science community and I’ve always tried to be involved in projects that do connect to the scientists, their research and so this looked like a good opportunity.

As curriculum project director, his chief interests and motivations for joining the NCDP included facilitating the curriculum development process by providing theoretical and practical knowledge of science education and curriculum development to the high school teachers and scientists. He was motivated by the opportunity the NCDP provided to develop “meaningful nanotechnology and nanoscience curriculum for secondary students” and to translate nanotechnology knowledge in meaningful ways that would lead to public awareness and understanding. These interests emanated from his overall view that the collaboration between scientists and teachers was essential to science education and the scientific field as a whole:

I think it’s very important in science education for teachers and students to learn about cutting edge research that’s going on and research that influences their lives or have some potential impact on their lives. So, the outreach that we have designed which is actually to produce science curriculum and working with expert teachers to produce it, I think can help accomplish this goal of disseminating this information and helping students not only be exposed but to learn about the different research protocols and the science behind nanotechnology and its applications... it’s very important, it’s a connection between science and science education and learning in the classroom of science becomes more meaningful as it is contextualized and part of contextualizing science and science learning in the classroom is to learn about contemporary research that’s going on that affects their lives, our students’ lives.

Thus, in the 2002 pre-workshop interview, Gary indicated that he was “very excited about the program” and hoped that the interactions achieved in the workshops would be reciprocal: the scientists would learn more about Science Education, teaching and secondary schools and that the high school teachers would learn more about scientific research in nanotechnology and be “energize[d]” and “rejuvenate[d]” by their exposure to “cutting edge science.”

Among the faculty and graduate student scientists, the opportunity afforded by the NCDP to bring awareness of nanotechnology to the public heavily influenced their enrolment. As Rachel so eloquently stated in my 2002 pre-workshop interview with her:

We're up on the fifth floor of Derring and most people in the department don't really understand what we do. So, if we can let somebody understand what we do, it's a feeling of success, success in communicating.

Melissa also became involved because of her interests in using the NCDP as “a tool to convey some of these things that the [scientists] are learning in the laboratory to the people out in the real world.” In my 2002 post workshop interview with her, she explained the following:

I mean science needs to be communicated to the public more so that the public can understand what scientists do all day because...a lot of the things that we do in science really affect people's lives you know in terms of, for the stuff I do it's groundwater contamination or drinking water supply, and so science does have a very important part in society, but as scientists we don't necessarily communicate that very well so I see that's why the outreach program so that we learn how to communicate better to public and to students that can potentially grow in terms of interest in science as well.

One of her primary interests was in getting others to “buy into [nanotechnology] and see the importance of it and the applications.” If this was achieved, “then there [would] be more of a push to have it in schools, more of an interest in students, maybe undergraduates will start have sort of more research interests as well.”

Charles was also motivated by the opportunity the NCDP provided for the Fisher Group to “pass down” information that would expose the public to nanotechnology:

One of the most efficient ways I think is through schools, through education. So, from that standpoint I think it's important to pass it down...And again, I think it gets back to maybe the bigger issue of how science and engineering are going to affect and impact the public in the future. If you don't know something exists, or anything about it, it's hard to have any, make any kind of informed decision as to whether you think this is good or this is bad or our tax dollars should be spent on this or they shouldn't be spent on it or so, information, knowledge is power is kind of one of those sayings that you hear and so, I think from that standpoint outreach is good because it helps inform the public about other types of scientific endeavor, whatever they may be.

Similarly, Terrence, James and Sam enrolled because they were interested in sharing the Fisher Group's research and nanotechnology with high school teachers who would pass it

on to their students, who in turn, provided they had an interest in science, would decide to make science their career and would make sound decisions about their future. They felt that bringing nanotechnology into the high schools by teaching high school teachers was the first step in bringing this new science and their research to public knowledge.

Furthermore, as Rachel commented below, they hoped that this awareness would lead to high school students' future enrolment in research at the university level:

...for the students, the project will encourage them to maybe try something they might have been scared to try in universities. I mean they may get so excited about the use of lasers in nanoscience that they'll go on and take these courses that they may have been a little bit afraid of before cause science has that scare factor – fear factor. And so, if it's taught well at a high school level, it will encourage people to take those at the university level...to excite bright young scientists in earlier stages.

For high school teachers, the ability to learn something new and to simply find out more about nanotechnology greatly influenced their enrolment. According to Kate, “having finished the CD-rom and the textbook project, so I was kind of wanting to do something else so that nanotechnology came up at the perfect time.” They also saw the NCDP as providing them with “a chance to get to know what scientists [were] doing.” Another interest for their enrolment in the NCDP was the desire of some teachers (Megan, Jenna and Kate) to debunk the following myth as expressed by Megan, “there [was] a lot of stereotyping regarding the isolation of scientists, that research [was] going on in the ivory tower and [didn't] come out until it [could] actually be presented in a product that [they could] consume.”

Teaching Experiences

For some scientists, their prior teaching experiences motivated them to enrol in the NCDP. For example, having taught several labs to engineers at the freshman and sophomore levels in Elements of Geology, Terrence communicated to his advisor, Steve

Fisher that he had a keen interest in teaching – an interest which could be attributed in part to his view that “science has a purpose”:

...I think as scientists we need to give back for a couple of reasons. One, quite frankly most scientists are spending taxpayers’ dollars, and I think a lot of people expect a return for that, and I think its important that we realize that we are working for...the public and working and developing our techniques and our experiments to generate knowledge that will somehow benefit that public. And I think it’s important to serve as an educator, you know either directly as a teacher...or indirectly by exposing students and K-12 educators to the scientific process.

Thus, Terrence’s view of the NCDP as “a branch of teaching” also influenced his decision to join.

Similarly, James was motivated to join the NCDP because of his love of teaching and prior experiences teaching a lab as an undergraduate one semester and Physical Geology, Mineralogy and Elements of Geology classes at Virginia Tech:

You know I can point to a ton of experiences. I’ve been a resident assistant when I was in high school. I taught Junior Achievement to...elementary school kids...I’ve done like Science Day at the mall. I used to do that every year where we’d go and kids would like come up and you’d show them neat things about Geosciences and you know, it’s just a blast and I love working with education and I love working with students but I’ve never had the opportunity to really learn from teachers.

Charles also admitted that he was interested in the NCDP because of the enjoyment he received from his prior teaching experiences as a graduate student and as a Navy official. His current employment position at Virginia Tech as a research post-doc did not afford him much time for teaching, and thus, he saw the NCDP as a way to get back into teaching.

Personal History

In the preceding section on human actors, we saw that scientists’ research interests were often motivated by personal life situations. For example, Rachel’s and Melissa’s childhood experiences with contaminated water supply led them to

nanotechnology research, that is, to seek practical ways to control bacterial transport in groundwater. In a similar fashion, some human actors' personal history influenced their enrolment in the NCDP. For instance, because of his "very fortunate" childhood experience in public schools that had "outstanding science programs", Charles saw his enrolment in the NCDP as an opportunity to help improve science education in high schools and the public understanding of science.

Also, in my 2002 pre-workshop interview with Terrence, he stated that outreach was "extremely important" to him. He placed a high "premium on it" and therefore, he was happy to join the NCDP. He then proceeded to express one of his motivations for his enrolment in the following way:

...my mother-in-law is an elementary school teacher and I would say maybe once every month, I'd get a phone call from her asking a geology question, something about volcanoes, something about rocks because she's teaching this section and, cause she's a science teacher as well and she's teaching this section...I get the biggest kick out of you know helping her out and giving her answers and then thinking about gosh what's the best way to put this to benefit fifth graders and then what it's going to do and then get the response of: oh, yeah Terrence you know we sent them, you know I sent my students out to that link you gave me and they loved it or I explained it to them in this way which I won't have thought of without talking to you and it really hit home. And you know that doesn't happen every time but when it does it just extremely rewarding for me.

One of the motivations which influenced James to join the NCDP was his own high school memories of the "small windows" where "once in a while [he'd] get into real science":

...like we had a guy from NASA come in and he'd talked about, you know and it was a very kind of elementary, rudimentary presentation but it still kind of gave you that little snapshot into what he does, you know what do scientists do, what does a space scientist do. And I just remember how exciting that was and so I think if, if we can kind of give those high school students a snapshot into what we do, a real snapshot too, you know what I mean, and stuff like experiments not working or you know an instrument breaking down, the sometimes arduous process of the scientific method and going through, you know and but still letting them know that when all the smoke clears it's kind of the thrill of discovery that keeps us going so to give them an idea of what we do.

He wanted to be a part of the project because he felt that the NCDP would allow him “to generate something really cool to take back to the students”.

In a 2003 post workshop interview, Sam confided that before joining the Fisher Group, he did not really know what nanotechnology was. Regretting that he never got the chance in high school, he became involved in the NCDP because he felt that it would “give the kids a chance...to at least understand where nanotechnology [was] taking them”:

...the high schools are the places where a person starts to think about the world in a serious way as such, at least what I started. So, if we introduce nanotechnology and we want nanoscience, nanotechnologists in the next ten years and huge bunches of them, high school is the right where you can push it.

Academic and Career Opportunities

The sociology of scientific knowledge, and more precisely interests studies, has shown that actors’ enrolment is not influenced by one set of “pure” interests or motives. In the NCDP, several participants had motivations for joining, which were not related to the project’s specific outreach goal. Project directors, scientists and teachers alike saw the NCDP as providing opportunities to enhance their portfolios and generate publications that could advance their careers. For instance, in her role as project director, Stacy felt that being on a million dollar NSF project would positively impact her professional career and provide opportunities to craft research ideas for her scholarly work.

Gary also joined the NCDP in part because he saw opportunities to pursue his research interests in science education. About three or four months before launching the first workshop, project directors conducted interviews with scientists. Through these interviews, Gary became intrigued with “the way [the scientists] describe[d] their

science,” the work they were doing and how it impacted society. Through the NCDP, he saw the opportunity to explore more fully specific research ideas that related to the nature of science, science dynamics in curriculum development, the nature and societal implications of nanotechnology and what that meant for science education. In a 2002 pre-workshop interview, he pointed out that:

...part of this project is, provides a rich opportunity to explore the nature of science, cause we learn about scientific research and how information is generated and...how science is generated is very important because as citizens, our future citizens it's important for students to understand the nature of science and be able to make decisions about the research that's generated.

Among the graduate student scientists, Terrence was motivated to join the NCDP because as the recipient of a Graduate Assistance in Areas of National Need (GAANN) fellowship from the U.S. Department of Education, which required him to obtain supervised teaching experience, he saw that his enrolment in the NCDP would fulfill this requirement. He also felt that his enrolment in the NCDP would help him learn valuable teaching skills from high school teachers, which could be used in his professional career. Secondly, he hoped it would provide an opportunity for the Group's research to help others learn about the whole scientific process.

For Sam, his experience in India where educators – the “high scientists” – were the ones in charge of creating curriculum influenced his decision to enrol. He felt that the NCDP provided a great opportunity for him to learn “how people like educators and like scientists sit together and come up with something that's constructive and how do they make the lesson plans.”

Some teachers were also motivated to enrol in the NCDP because they too sought academic and career opportunities. For instance, Julie saw the NCDP as a way to expand her professional interests. In the 2003 post workshop interview, she explained that she

always tried to stay involved in other projects because although she loved teaching, she did not think she “could do it year after year if [she] didn’t have something special to work on that was different, like a grant at Virginia Tech.”

For some teachers, the NCDP was an opportunity to pursue academic interests. At the time of the project’s inception, Megan was in the process of starting a Masters degree in Curriculum and Instruction at Virginia Tech and so, she felt that her involvement might lead to “a good Masters thesis.” Anna was also strongly motivated by her personal desire to pursue her Masters degree and saw the workshop as a good opportunity to “check out grad school.” And, when Anthony heard about the outreach project, knowing that nanotechnology is an emerging field, he saw it as a good opportunity to “ride the bubble” by using nanotechnology as the focus of his dissertation.

Prior Affiliations

Prior affiliations played an important role in influencing human actors to enrol in the NCDP. Before the NCDP, Stacy and Gary worked together on a number of outreach projects and thus, when the Fisher Group needed an external assessor, Stacy asked Gary to fill that position. Prior affiliations with project directors on similar collaborative projects also led some teachers’ to join. For example, in the 1980s, Megan worked with Gary – the curriculum expert – and enjoyed that experience. She was also acquainted with Stacy, stating that she “had heard great things about [her]” and decided it would be a good project to join.

Kate worked on several projects with Stacy before and was personally contacted by the latter to solicit her involvement. As a teacher-in-training in the Department of Teaching and Learning, Anthony worked with and was one of Gary’s students. Prior to

the NCDP, Julie also worked with Stacy and when she joined the project, she also knew Gary as she was one of the Masters' students in the Department of Teaching and Learning.

Some teachers were also influenced by their prior affiliations with Virginia Tech and the Geosciences Department. For example, Megan pointed out that “when I saw the advertisement for it and it was you know NanoBioGeoChemistry and I thought, oh, I majored in Geophysics in college so it sounded really exciting to me since it was getting back into the Geology Department.” And, Daniel was motivated to join because he confided that although he was raised by his parents and grandparents to go to Virginia Tech, he did not attend. He was therefore “excited” to have the opportunity to work at the university.

Monetary Gain

Because all project directors and scientists were principal investigators and/or a part of the Fisher Group funded by the NSF grant, they were received a stipend regardless of their participation in the NCDP. However, one motivation for high school teachers' enrolment in the NCDP was the financial compensation they received (five hundred dollars per summer workshop, including travel and food expenses). According to Anthony, he was motivated to join because of “the monetary value that came along with it”. Kate also indicated that money was a motivator that influenced her enrolment:

“...like all teachers our time off in the summer is very valuable and just the little, you know the stipend that they gave us helped. So, okay well something I wanted, I want to learn about, I'm gonna get paid some money and you know, it works out both ways. It was good.”

Requirement

All principal investigators (PIs) in the Fisher Group, which included project directors, faculty scientists and two graduate student scientists (Terrence and James) were involved in the NSF grant writing process. Therefore, based on the NSF approval and allocation of funds, they were also required to be involved in the outreach workshops. As Melissa noted, being a PI on the grant meant that “there [was] a science aspect and there [was] an outreach aspect that [they] all bought into it.”

Graduate student scientists – Rachel and Sam – who joined the Fisher Group after the grant had been written became involved in the outreach aspect primarily because it funded their research. Rachel jokingly admitted, “I was told to”:

...we are funded. I’m speaking for myself now. I am funded by this NSF grant and it’s supporting my research, so this is my job. So, this is a component, you know 20 hours a week we get paid to do research, outreach is included in that. So, we are being paid for this. I am being paid for this.

Thus, a significant contribution of this study to Latour’s notion of interests is the finding that scientific networks are sometimes built and grow not merely because actors’ interests become aligned, but also because actors’ enrolment is mandatory. In this case, it was an NSF requirement and thus, project directors and scientists were compelled to join the NCDP.

Nonhuman Actors

As I intimated at the beginning of this chapter, when we talk about following the actants, we must also look at the nonhuman actors. In this section, I return to address the first research question:

- What actors were enrolled in the nanotechnology network?

Here, I describe the role of nonhuman actors utilized in the NCDP. As Latour (2002: viii) so eloquently surmised in his book, *Aramis*, "...sociology is not the science of human beings alone...it can welcome crowds of nonhumans with open arms...Our collective is woven together out of speaking subjects, perhaps, but subjects to which poor objects, our inferior brothers, are attached at all points. By opening up to include objects, the social bond would become less mysterious."

These "poor objects" – the laboratories, tools, machines and instruments – are important in expanding scientific networks because they help construct scientific knowledge. As Latour (1987: 91) pointed out, they are "powerful enough to define reality." This is evident in nanotechnology: without the instruments, scientists cannot hope to see at the nanoscale. As James, in a 2002 pre-workshop interview rightly stated:

Well, you can fund and fund and fund...but if you don't have the technology, if you don't have the knowledge, I mean the reason they're doing it is cause they've got the microscope that can do it. If that hadn't been developed all the funding in the world wouldn't do it...you've got to have that fancy equipment...the scanning force microscope...to see at the scale, to measure at the scale. That's essential. You have to have it. You have to have a tool.

Without these objects, a scientist could not conduct his or her research. For example, at the time of the first workshop, Rachel's research interests focused on the hydro-dynamic and interfacial forces that were associated with bringing tiny particles together and preventing them from being transported over long distances in the ground. To accomplish this, she worked primarily with an instrument called an optical tweezers, which she described as "essentially the Star Trek tracker beam":

...if you have ever seen a Star Trek episode and one of the spaceships will emit this enormous beam of light and trap another spaceship and be able to maneuver it and manipulate it in space, that is what optical tweezers do, but they do it at the nanoscale at a very, very tiny scale. So they use an intense beam of light from a laser, like a laser pointer, and they focus that through a microscope objective and the pressure that is associated with that light when it is focused so tightly it's strong enough to levitate little tiny objects in space and move them all around.

Though invented in the early 1980's, the optical tweezers were mainly used in Physics and Biomedical Engineering. In fact, because it was not available on the Virginia Tech campus, Rachel frequently traveled to the University of Virginia (UVA)'s Biomedical Engineering Department to conduct her experiments. As this instrument was rarely used in Geology, Rachel speculated that she was probably one of the first people to use it in this line of work. However, after experiencing difficulties in getting access to the optical tweezers because of competing interests for equipment use and time from University of Virginia (UVA) students, Rachel had to abandon her research in that area.

At Virginia Tech, the Geosciences Department was equipped with several million dollars of scientific instruments, computers, machine shops, several electronics shops and a photographics lab. In addition to two (2) computer labs for teaching and supporting computation-intensive courses, the Department had approximately twenty (20) labs, including, the 3-D Subsurface Imaging Laboratory, the Aqueous Geochemistry Lab, the Chemical Hydrogeology Lab, the Crystallography Lab, The Electron Beam Lab and the Fluid Research Lab, just to name a few. All of these were equipped with a range of experimental and analytical facilities and supervised by specific faculty members. In the NCDP, project directors, scientists and teachers primarily used the Mineral Surface Chemistry (MSG) Laboratory and the Atomic Force Microscopy (AFM).

The Mineral Surface Geochemistry (MSG) Lab

According to Callon, Law and Rip (1986: 223), the laboratory is “a locus where force is concentrated and packaged so that it can be sent out to exert influence at a distance.” The sociology of scientific knowledge (SSK) literature has consistently revealed that for scientists, laboratories exercise social power. They provide primary

sources of authority and legitimacy important in building and expanding scientific networks. “The laboratory is more than the physical space where experiments are carried out... the laboratory is itself an important agent of scientific development. [It] is...the locus of mechanisms and processes which can be taken to account for the success of science” (Knorr-Cetina 1992: 116).

Situated on the fifth floor of the Geosciences Department building and supervised by Steve Fisher, the MSG laboratory maintained a modern wet-chemical laboratory and various laboratory computers, including an Alpha workstation. On entering the laboratory, I observed that it was very well lit with many bright fluorescent desk lamps, each situated directly above work areas because scientists usually worked with very small objects like cantilevers and tips, which ranged from ten or fifteen to a few thousand dollars. Colorful images and posters of nanoparticles, atoms and molecules, along with some scientific literature, were taped to the laboratory walls. There was a huge Nanotechnology Calendar with the words “NANOTECHNOLOGY IS THE FUTURE” in bright, bold colors.

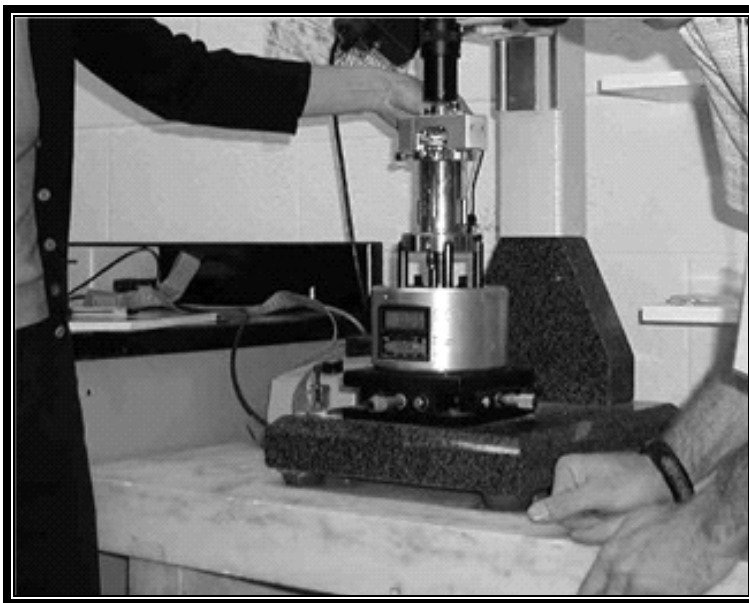
Although, the workspace was small, approximately four to six hundred (400-600) square feet, the cramped atmosphere was alleviated by what Charles jokingly referred to as the “most important tool” in the room: a music box or cassette player. Because scientists spent a great deal of time in the lab, Charles said the music acted as a “stress buffer.” There were many other tools and instruments in the laboratory like several personal computers, which constantly recorded data so scientists need not to be physically present to monitor reactors at all times. Each instrument or machine was positioned in separate corners, giving the initial impression that the workspace was

specialized and territorial. However, Rachel indicated that no one scientist was restricted to any one instrument but could use a range of instruments as his or her research required. Yet, scientists continued to stake their claim to particular instruments with such comments like “I work with this” or “Terrence works with that.” Workspace and scientists’ references indicated division of labor, that is, that their tasks were specialized.

The Atomic Force Microscopy (AFM)

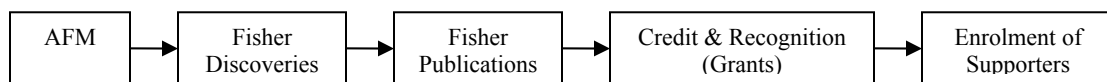
Machines, instruments and tools also play significant roles in network construction and growth. According to Traweek (1988: 160), they are like “eyeglasses” through which scientists are able to “read and then, decipher the fixed text of nature.” In the NCDP, the MSG lab contained the primary tool scientists used to engage high school teachers in practical exercises and applications during workshop lab sessions: the AFM as photographed by Rachel in Figure 4.2. This was a scanning tunneling and force microscopy that enabled scientists to image the surfaces of materials down to the atomic or molecular scale and to measure forces between individual molecules.

Figure 4.2: Photograph of the Atomic Force Microscopy (AFM)



In the laboratory, it was bolted to a marble table. This, scientists explained, helped “to damp out vibrations from the air conditioner unit.” The AFM “need[ed] stability” and the fact that their lab was located on the fifth (5th) floor where motion affected results were reasons for securing it with bolts. Much like the detectors in Traweek’s (1988) study of physicists, for the Fisher Group, the AFM functioned as its “signature.” It enabled them to lengthen the size of the network in the following way:

Figure 4.3: Nonhuman Actors Lengthening Nanotechnology Network



Inscriptions

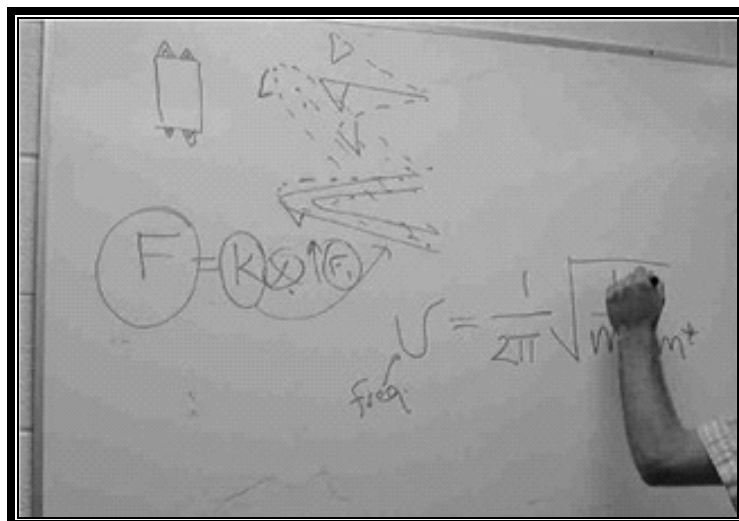
Only recently has the role of inscriptions and rhetorical devices (e.g. narratives) begun to receive more attention (Bastide 1990; Knorr-Cetina and Amann 1990; Latour 1987; Lynch 1985). According to Roth and McGinn (1998: 216-217), inscriptions have three main functions. First, in science and technology they are used to constitute the objects of interest. For instance, a graph is used to constitute a particular phase transition as “fact” (Woolgar 1990) and an engineering diagram of an airplane wing specifies a particular design (Henderson 1991).

Second, they coordinate work across different communities of practice, across time and space, functioning as boundary/coherence objects because they find or define the boundaries between communities of practice and coordinate (making coherent) activities across these boundaries (Fujimura 1992; Star 1989a). Third, inscriptions are also conscription devices (Henderson 1991) that organize collaboration and coordinate the contributions of group members. The construction and use of inscriptions is one aspect of convincing and aligning others to scientific claims.

Throughout the workshop, scientists utilized many inscription devices. For example, on the first day of the workshop, binders were distributed to everyone containing research articles, workshop experiments, worksheets, exercises, links to nanotechnology websites and PowerPoint lectures notes accompanied by pictorial demonstrations of techniques, equations, formulas, graphs and charts. During the workshop, structured exercises, worksheets for plotting graphs and tracing nanoparticles, guessing games, visual aids like photos, images, diagrams, rough sketches and illustrations were also employed to teach and persuade others of the credibility of nanotechnology claims.

Roth and McGinn (1998) also point out that these devices are so important that scientists and engineers will stop a meeting to fetch a design drawing, produce a facsimile on a whiteboard or render a diagram in gesture. On several occasions during the workshop, I observed scientists doing just that: they used inscriptions like the one I photographed in Figure 4.5 when they wanted to better illustrate or convey their message to teachers.

Figure 4.4: Photograph of Scientist Using Inscriptions as Persuasion Tool



During the workshop, scientists also enlisted the narrative as “forms of argument...to convince actors to adopt a particular position” (Clarke 1992: 87). On several occasions, narrative accounts or storytelling of how scientists came to be involved in nanotechnology, their research and interests, as well as the story of how nanotechnology came to be “cutting edge” science were utilized to persuade teachers to accept nanotechnology claims. The following transcribed and edited excerpt from Charles’ lecture on the “General Overview of Nanoscience and Technology” during the first day of the workshop exemplifies this point:

...over the course of the last couple a hundred years, as science has developed, we first start looking at things that we could physically observe with you know your mark 1 mode zero eyeball. So things at the meter scale, dimensions we’re familiar with and then, in the 17th and 18th and 19th centuries as we began to develop optics, we went to both extremes. We came up with telescopes, so astronomers started looking out here in the big range and looking out into space and they’re looking at things, and also microscopes were developed, so we started going this way, so starting of here at about a meter, going to the smaller scale...And then, the early part of the 20th century, the last century, nuclear physics began to be developed and we had ideas about atoms and molecules and how things are the large scale were really made up of really tiny, little bits. We didn’t exactly know what those bits were, how to image them but they were made up of very small things and the theories of molecular and atomic physics were developed. We began to harness nuclear power both in constructive and destructive ways in the 20th century, the first half of the 20th century. But we couldn’t really image those things and there was this gray region in between called the nanoscale. So, we’re between the subatomic scale of subatomic particles and the things we can see with microscopes...

These devices had the effects of keeping participants engaged, communicating information across communities of practice and making the world visible to the audience. By persuading high school teachers of nanotechnology’s role in society, scientists were able to effectively mobilize them into the nanotechnology network.

Summary and Conclusions

This chapter described the enrolment of actants in the knowledge education production processes in the NCDP. In this case study, we see that both human (project directors, faculty scientists, graduate student scientists) and nonhuman (laboratories, machines, inscriptions and rhetorical devices) actors were enrolled. Their enrolment in the NCDP had the effect of increasing the number of supporters around nanotechnology claims, thereby expanding its network. The situational context of the Virginia Tech campus where outreach is a mission provided an inlet or space for the insertion of the NCDP, which drew high school teachers into the network.

The Fisher Group and the NSF contributed significantly to the growth of the nanotechnology network. The Fisher Group, through its expertise, research interests, discoveries, inventions and publications, provided the necessary conditions for NSF funding. In a Latourian sense, it functioned as an obligatory passage point through which other actors became linked to the nanotechnology network. In supplying the funds to the Fisher Group and through its outreach component, NSF provided the basis for expanding the network: the NCDP, which in and of itself was a type of enrolment strategy for expanding the network. It created a framework for the Fisher Group to enrol and mobilize others – project directors, high school science and math teachers, graduate students, evaluators and eventually, high school students. Its reputation as a legitimate authoritative structure influenced teachers' voluntary enrolment in the network. As teachers became involved, the size of the network expanded.

Equally important to this case study was an understanding of the enrolment of nonhuman actors – labs, instruments, machines, inscription and rhetorical devices. These

helped scientists and teachers “see” at the nanoscale and served as sources of authority and persuasion to give credibility to the scientific endeavor. Without them, scientists in the workshop could not hope to verify claims and mobilize new actors to nanotechnology claims, thereby lengthening the size of the network.

This case study showed that interests and motivations are essential elements in network building and growth. Several actors’ professional and personal interests and motivations influenced their enrolment in and their link to the network: expertise, rhetoric, awareness, teaching experiences, personal history, academic and career opportunities, prior affiliations, monetary gain and requirement. These interests and motivations provided the basis for actors’ participation in the NCDP and thus, the growth of the nanotechnology network.

They also revealed that there is no one set of “pure” interests and motivations that influenced actors’ enrolment in scientific networks. Rather, consistent with the sociology of scientific knowledge (SSK) research findings which debunks the notion of science as devoid of values and interests, scientific pursuits are products of their political, economic and cultural milieu. As Longino (1990: 37) rightly noted, “...social and cultural values play a role in scientific inquiry.”

¹ All human actors are identified by pseudonyms.

Chapter Five : DECONSTRUCTING THE NETWORK, PART I INTERNAL STRUGGLES

In this Chapter, I explore the notion of conflict or contradiction **within** a node. Specifically, I address the following research question:

- What internal factors affected the network?

One might be inclined to ask: Can we really use the term “internal” when we speak of networks? In Chapter Two, I showed that when making distinctions between systems and networks, Hughes (1986) aptly noted that a network does not have an “outside.” From this formulation, it is inappropriate to see the network configuration as having an “inside” and an “outside.”

However, as I have also shown in Chapter Three, a node can be an organization, a government agency or a workshop. Each of these nodes consists of several other linking nodes whose work, values and interests may differ from each other. Herein lies the potential for “internal struggles” among nodes, which is the focus of this Chapter. Within any group, regardless of its collaborative efforts, where people’s perceptions of their roles, their levels of expertise, their authority and status are heavily involved, there is always potential for conflict. Chapter Five identifies and examines several internal factors that led to conflict: decision making and control, personal interests and agendas, enrolment strategies, labor distribution, communication and feedback, gender and race, and financial compensation. I conclude this Chapter by showing how these factors affected or could potentially affect the configuration of the nanotechnology network.

Although school and university partnerships have existed for some time, the concept of collaboration has only recently become a distinguishing feature of the late

twentieth century (Verbeke and Richards 2001; Patterson, Michelli and Pacheco 1999). While the universities' recognition of the necessary role of schools, and schools' acknowledgement of the importance of teacher education have been, for observers like Fullan, "the most salient change" in recent years, one challenge to collaboration is the inevitability of conflict among participants. Sociologists have long been involved in the study of conflict. For instance, Marx and Engles' (1848) pivotal work on the *Communist Manifesto* begins with the assertion that "the history of all hitherto existing society is the history of class struggles." This inevitably leads us to consider questions of conflict, power and inequality.

Within science studies (STS), these struggles are widely approached by studying interests and controversies. Actor-network theory (ANT) has also broached the subject less explicitly by investigating the success of technological innovations and describing heroic failures (Grint and Woolgar 1997; McMaster, Vidgen and Wastell 1997; Latour 1991 and Latour 1996 [2002]). Implicit in these studies is the question of why things do or do not work. It is not my goal here to evaluate the success or failure of the Nanotechnology Curriculum Development Project (NCDP), but to point out that these inquiries help us see that conflict is part of the interactions and associations in scientific networks. According to Hughes (1987: 73), these conflicts can be classified as "reverse salients" – "components of the system that have fallen behind or are out of phase with the others." Basically, these are hindrances or setbacks that may affect whether or not the network is a success or a failure. They therefore have the potential to alter the configuration of the network by decreasing its size.

Decision Making and Control

One of the requirements for building collaborative relationships in school-university partnerships is “equal participation in the decision-making process” (Million and Vare 1997: 711). Hall (1998: 123) points out that power is important to decision making since it is the power holders who have the ability to shape and decide, i.e. control, what are issues and what are nonissues (Ranson, Hinings and Greenwood 1980; Clegg and Dunkerly 1980).

Initially the NCDP began as an effort to “build teams” based on democratic group participation and collaboration. Ideally, this meant that all participants would have equal say in all processes involving curriculum development. However, from its inception, most of the decision making and control lay in the hands of project directors. In the first week of June, project directors organized the first planning session for participants “to sit down together to plan how [their] time in June [would] be spent.”

At this session, project directors gave participants written drafts of the “Workshop Agenda,” “Goal and Strategies for the Educational Component of Nanoscience Project” and “Agenda – Planning Meeting for [Nanoscience Workshop – June 17-20, 2002]” and workshop activities were outlined as follows: “Day 1: Introduction; Day 2: Data Collection; Day 3: Curriculum Planning; Day 4: Long Term Planning.” Although participants examined and critiqued these drafts as well as voiced their concerns and expectations, decision making and control remained in the hands of project directors. It was their decisions that ultimately defined and set forth the workshop agenda, activities and objectives.

Despite project directors' vision that scientists would be in control of presenting nanotechnology information on the first day and then, the second day "would be the teachers' turn to reciprocate," this was not the case. In light of the challenge of "trying to condense four years worth of work" into a one week crash course in nanotechnology, the transfer of control to teachers proved difficult during the first workshop. To accomplish the goal of bringing nanotechnology into high schools, within the first year, scientist had to teach the teachers the basics of nanotechnology. Scientists' expertise in this field and teachers' limited knowledge meant that scientists largely decided and controlled the content, scope and format of nanotechnology information presented to teachers. They were also in control of supervising high school teachers in hands-on research in the laboratories.

Among the scientists, there were varying levels of control and decision making. In the first workshop, much of the responsibility of teaching and supervising teachers rested in the hands of the graduate student scientists. By the end of the first workshop, it was clear that graduate students were "running the show," not the faculty. This did not mean that some faculty gave up control freely. For example in a 2002 post workshop interview, Charles indicated that he felt he should have had more leadership. This, he tried to achieve during the workshop, by interrupting graduate students during their presentations to correct or clarify points. This resulted in some tension between the scientist and the graduate students who felt that he was "taking over" and monopolizing their presentations.

Also, among the graduate students, some had more control than others. For example, in the Atomic Force Microscopy (AFM) laboratory session, although Terrence

and Rachel were both responsible for instructing and directing teachers in hands-on tasks, I observed that Terrence was the “lead” decision maker. He derived this position mainly because of his extensive experience working on the machine for his research. Therefore, he was mostly in control of guiding teachers through the lab, explaining the instruments and images generated from their experiments.

In the first workshop, teachers generally had little or no control. As one teacher pointed out, “[we] mainly were being informed. We were being taught what was going on and being allowed to experience some of it.” There were however some instances in which decision making was collaborative: teachers’ lack of knowledge meant that they had to rely on scientists’ opinions and advice to determine the appropriateness of incorporating technical materials and instruments for high schools; and scientists’ lack of knowledge about high school protocol meant that they had to rely on teachers for advice on what activities could realistically be implemented in high schools. For example, at the end of the first workshop, participants decided that one of their goals would be to purchase an inexpensive AFM to use in a traveling laboratory. When scientists explained the difficulty with such a plan [the AFM being a highly sensitive instrument requiring a very stable environment and constant maintenance], teachers willingly abandoned this goal. Likewise when scientists suggested that high school students collect bacteria samples from nearby ponds, after teachers informed them of school health and safety issues, they willingly sought other learning tools.

Toward the end of the first workshop, teachers began to make significant decisions about practical ideas that could be integrated into specific lessons for high school students. On the third day, when asked to separate into two groups [scientists in

one group and teachers in another], to formulate practical curriculum ideas, the teachers took the lead. They provided scientists and project directors with several ideas. In Biology, they suggested that students be shown photos of microscopes, and/or they could talk to their students about proportions and scaling. For each subject area, teachers developed similar ideas and themes that they felt were suitable for high school students. On the other hand, the group of scientists did not develop any ideas. Rather, they discussed their own concerns about time constraints and graduate student turnover. It was during this session that scientists redefined their role for the second workshop as “technical consultants available for questions and advice.”

This redefinition of their role as “consultants,” as well as teachers’ expertise in a real classroom setting, led participants to agree that for the second workshop, teachers would take more control and lead in curriculum development. To some degree, the transfer of control was achieved in the second year. In fact, scientists felt that while “[the teachers] were more like students, and we were teachers” in the first workshop, during the second year, “the teachers had a much stronger role in what was going on.” Control and decision making were “more equal.” According to Kate, one of the teachers, the second workshop was a “very, very different process”:

This past summer was a lot better than the summer before, just basically because we know each other so we had to get across that bridge of getting to each other and kind of looking each other like alright what are they doing on this project, what is she doing on this project and what does she want to get out of it or what does he want to get out of it and you know, are we gonna to get together, are we gonna be able to work together, well you see now that last summer, we knew we could and we knew we were a team and so, I guess what I’m saying is the first, the first week, first year, was all important because you’ve got that learning curve that you’re learning about each other, what the project’s about and working together and the scientists and everybody blending together and then of course last summer we were already blended and so, yeah, so it was just, it was just going back and you know, seeing old friends and old buds and working on, you know, getting and also too we were able to do more work in the lab than sitting down.

Teachers appreciated the changes where they were given the opportunity to be more involved in explaining and informing scientists of what experiments and lessons might or might not work in a typical high school classroom. This brought a sense of pride among teachers as Anthony explained in a 2002 post workshop interview:

...I think one thing I enjoyed about the conference is, is the graduate students and the people involved, because last year, it seems as we were always in this room ever, getting talked to about, you know nanoscience. And it was like being talked to, but this time, we were talking with one another you know. And, I was just looking at faces during the [guest speakers'] presentations, and I saw like intrigue, intrigue on [the scientists'] face... They were, they were actually learning like what is a rubric and what is inquiry and all these words. It was like, it was like a give and take information time, this time, you know, cause like [one scientist] was saying like I wished I would have known this three years ago before I taught in my GA classes and stuff, and so they can see that you know there's other ways of teaching and you don't have to be this rigid person all the time. And I just enjoy that seeing, causing they got value out of what I do, as well as me getting value out of what they do also.

However, a closer look at the workshop activities revealed that the control and decision making processes to some degree remained unequal: scientists and project directors still maintained the power. They made the decisions about workshop presentations, agenda, goals and activities during the second year. For example, on the first day, Stacy – the outreach project director – took the lead outlining the workshop schedule, goals and objectives.

Also, though it was previously agreed that teachers would lead in producing and driving curriculum content, decisions about identifying and developing themes for curriculum development were directed primarily by the scientists. On the first day, before participants began collaborative deliberations on curriculum themes, one faculty scientist gave a thirty (30) minute presentation where she outlined specific themes that could be used in lesson plans. The themes were based on the strength of the research Group in “Earth Processes.”

Since the Fisher Group's research focused on "Earth's Environment," she suggested that teachers adopt that theme to develop ideas for lesson plans. Under this theme, they could emphasize such topics as "Nanoparticles and environment," which related to the reaction with contaminants, mineral dust and human health, and the recognition that minerals at nanoscale behave differently than at the large scale. Or, they could focus on "Microorganisms and environment," which involved plant and soil nutrition, nutrient cycling, waterborne diseases and remediation of contaminants. From these major categories, she further proposed drawing a link between waterborne diseases, that is, the big problem of pathogens in water and the public health would be a feasible way to develop lessons.

To further persuade teachers that "pathogens in water" was the most appropriate theme, she utilized the following statistics: 20% of world lacked safe drinking water; 1400-9400 deaths per year in the U.S. were related to water borne diseases; and worldwide, waterborne diseases caused 250 million illnesses per year and 10 million deaths per year. Several researchers (Dickson 1984, Porter 1995, Rose 1991) have documented the power of hard numbers or statistics to provide legitimacy to administrative and/or political actions as they bring a "kind of objectivity" as truth claims. In this regard, Porter (1995) aptly noted that statistics not only describe social reality but they also help define it. Although the final choice was left open for discussion, the statistics presented by Melissa left such an impression that teachers were easily convinced to develop lesson plans in accordance with scientists' directives.

As it pertained to the actual production of lesson plans, rather than have the teachers decide what might be the best fit for their classrooms, I found that because

scientists were in authority positions they could effectively make and control decisions. The type, the theme and content of lesson plans were therefore driven by scientists' specific research interests, focusing on microbe-mineral interactions and on sustainability of water supply; themes which scientists successfully convinced teachers to adopt as observed in the following comments from two of the teachers, Megan and Jenna:

...I see that as the overarching theme of what we're doing here. It's the idea that we live on this earth and that, you know, what is the saying if it's not grown, it's mined, and that the things you mine, you know, there is a finite amount of all of these resources that we depend upon. So, sustainability is how we're gonna use those so that we can keep living life the way we want to live it, things like water that get recycled and other things that don't get recycled.

...I think a lot of teachers from Chemistry for example teach the Chemistry content and, but if there's a way that it could tied into the environment for example, I think it appeals to other students but then, there are ways you can talk to the students about, getting them more connected with something that's going on right in their community, and making sure that whatever that is, it's sustained and there's not a sewer line that goes through it, or something like that, or it's not paved over for a soccer field or something like that, but you're really looking at issues that people have different values about, and, but sustaining something, and to me, the opposite is changing it, then you can't, you can't ever get it back. And, you know people just don't, they forget that if you know, you take this 40, this 40 foot trip along Tom's Creek and put in a sewer line and that's never, ever can you get that, get back, whatever the lifeblood, whatever was there you can't ever get back. So, we need to try to sustain that instead of changing it, and, but we don't always bring those issues to a Chemistry class though, maybe in Biology they do more of that, but in Chemistry we just don't do very much of that. We need, we need encouragement to do that more.

Although scientists said that they were going to act as consultants, their involvement in the second workshop was still very hands-on. This was so because teacher's lack of expertise and knowledge in nanotechnology led to a dependence relationship that compelled them to accept scientists' claims: "we really need them cause, to go from where we are and what we know from so many different areas and then, to relate nanoscience to what we're trying to do, I don't think we could have done it without them."

For both the scientists and teachers, the ability to make choices about pedagogy and models for curriculum development were limited. Prior to the second workshop, these were predetermined by Gary who formulated his own set of “Nanoscience Lesson Plan Guidelines,” which he distributed as a handout to participants. Since the project was a national endeavor, Gary indicated that the team should develop lesson plans using inquiry-based models as advocated by the National Standards:

The Nanoscience lesson plans should be designed to be inquiry-based, following a sequence of instruction that engages students in active learning, scientific discourse and scientific investigation. Thus, we are recommending that the 5-E¹ Learning Cycle Model be incorporated to promote student inquiry and consistency among Nanoscience lessons. Each lesson(s) should address a socially relevant issue and be accessible for all students.

In his forty-five (45) minute presentation, he explained how participants should develop nanotechnology curriculum within the recommended framework and engaged them in a practical inquiry-based activity involving an instructional tool called the KWL worksheet – an acronym for “Know, Wonder and Learn.”

The object of this exercise was to determine what participants already “Know” and what they always “Wondered” about inquiry-based instruction. After an open discussion, some felt unsure of using this method to develop nanotechnology lesson plans. For example, Megan wanted to know how to recognize a good situation for inquiry and indicated that that it was difficult to undo something once students already saw things in a certain way. James, a graduate student scientist, openly voiced his concerns in a 2003 post workshop interview about using the model Gary proposed without exploring other methods:

I guess, I wonder, because I don't know anything about this really, and you're clearly coming in advocating an inquiry based model probably based on the National Standards and all that kind of thing. And clearly there are some other people that say well, that's hard to do in the classroom. So, my thought was well

what are the other choices that you have other than inquiry based. There must be some other.

Although Gary's guidelines informed them that the inquiry-based model was merely a recommendation and not the only framework, despite participants' objections, he did not identify or propose any other models. Rather, to further convince them that it was the best model, he distributed samples of an inquiry-based lesson plan. Later in a 2003 post workshop interview, addressing the scientist's concern, he stated:

In my role, I wanted to give him what I felt was you know sort of the state of the art inquiry model for teaching, but I was really kind of caught, I didn't want to impose it on him too much and if they had gone other ways that would have been okay, but they seemed to jump right through it, and they wanted the example that I gave from my students, as a model to go by. I think, sometimes you have to use a different expertise to speed things up, rather than just sort of reinventing the wheel. So, well here's a good model, let's go for it and see.

These disagreements show that those holding the official positions of power and authority to make and control decisions were able to push their ideologies and perspectives chiefly because other actors lacked the knowledge and expertise to resist.

They also revealed that there was conflict among "experts." For example, in earlier discussions, project directors emphasized that part of the goal was to produce a compact disk (CD). However, scientists objected to the idea because in the past, their own teaching experiences with CDs were ineffective. One revealed that her students usually think a CD would be "fine in a homework format" but generally question "why they have to do this in the classroom if they can do it on their computer at home." She also pointed out that reaching lower income schools which often lack computer facilities or that differences in computer capabilities among schools could pose serious problems if they were going to use a CD as their primary dissemination tool. Another felt that there was "nothing like a human being there explaining." Despite these concerns, the outreach project director continued to promote the idea of a CD.

Scientists and teachers did not always agree with the decisions made by project directors. For example, with regard to the workshop schedule while Stacy felt that the four days assigned for curriculum development during the second year was “enough time,” scientists and teachers felt differently as Sam pointed out that:

The meetings should have been extended...they should have at least, not like, 8 hours a day, three day meeting. No. That's not good for me. It's like four hours or 3 hours for one week. Take it two weeks. Spread it out. But don't like try to cram people into a room and say, come up with something, come up with something, it's not enough. You have to like think by yourself, then probably discuss and then work on the stuff...we should be having a little more time on making this curriculum because all we were told in the initial schedule, it was like brainstorming sessions, brainstorming sessions, and I was not exactly clear about what I should be brainstorming upon. I have a brain, I know, but.

And, Jenna indicated that “four days did seem kind of short” and “it would have been nice if we'd had that fifth day.” Kate also agreed that instead of four days, they should have had at least a week: “I would feel a little bit better if we had at least one more extra day cause right now I'm pretty rushed to get this done and so, one more day would have helped.” Contrary to Stacy's opinion that teachers would not be willing to have more time even if they were paid more, Jenna confided in a 2003 post workshop interview that she had no problem with lengthening the workshop:

Well, I think we need, I think the grant should have, and maybe it did fund more time that I'm not aware of. But I really think that just having four days, this summer is not adequate. You know, I really, I would really like to have had it be about three more days to work so that we could pull stuff back together and maybe even really fine tune so that we walk out here in three more days and we've got it, a packet. Having all the rough drafts stuff really bothers me, you know when I stop this, I want to have it ready – a good rough draft – not something with still a lot of holes in it.

Project directors frequently made decisions without consulting either the scientists or the teachers. For example, one of the activities decided by the project directors was to involve scientists and teachers in professional meetings like the Virginia Association for Science Teachers (VAST) and the Geological Sciences Association (GSA). On the last

day of the first workshop, Stacy revealed that she had already written an abstract for VAST and proposed that others collaborate to produce additional abstracts. Although teachers were willing to attend such meetings, this created some conflict for scientists who were not only unaware of the structure of VAST, but questioned why teachers would want them to attend. They were concerned that teachers had not acquired the level of familiarity with nanotechnology necessary to do abstracts and present at conferences like VAST and GSA. However, the project director continued to encourage them to participate.

Personal Interests and Agendas

The literature in the sociology of scientific knowledge (SSK) emphasizes that the scientific actors have interests, which can affect alliances in a network. For instance, Hughes showed that inventors, scientists, engineers, etc. often have vested interests in growth and durability of a system. To achieve their interests, actors usually try to convince others by mobilizing supporters, tools, rhetorical devices, etc. so as to create an alignment of the other actors' interests with their own. When these interests align, the network stabilizes and claims become facts, but when interests clash, conflict occurs. This has the potential to destabilize the entire network.

In the NCDP, I found that those in authority positions often used their power to pursue their own interests or "agendas," which occasionally created "bottlenecks" in the network. For example, Stacy's enrolment was motivated by her personal agenda of leaving a "legacy" of outreach in her Department. To this end, she arranged many socializing activities – breakfasts, lunches, dinners – to foster team building. However,

these tended to consume valuable time which created conflict within the group. As

James indicated:

My main thing was that it seems like if we have coffee and refreshments starting at 8:15 but we're not actually working until 11 o'clock, that that's not very efficient...for me, it was we've got from 9 o'clock in the morning til 5 o'clock to work, so let's work. And when we spend 2 hours at lunch, and 2 hours in a seminar, and 2 hours trying to get equipment to work, then we're really only working for 2 hours for the whole day.

From the graduate student scientists' perspectives, pursuing her personal outreach agenda hampered the group's progress in developing lesson plans in a timely fashion.

Another example of the conflict brought about by pursuing personal agendas occurred on the first day of the 2002 workshop. In Chapter Four we saw that Gary's role as assessor changed because his own research interests conflicted with assessment goal. In the first workshop, he pursued this agenda when he directed a forty-five (45) minute pre-curriculum writing exercise and discussion period. For this session, scientists were excused and high school teachers and project directors were left to discuss "curriculum issues." Teachers were provided with a list of questions (Appendix C) to answer individually and then discuss collectively. Although the session was identified as a "pre-curriculum discussion," the title of the questionnaire, "Nature of Science and Science Teaching" revealed that its primary purpose was to facilitate Gary's research agenda: "these questions are designed to stimulate discussion and to assess our knowledge and values related to the nature of science, scientific research and science education."

Many questions were ambiguous and teachers had difficulty in responding to questions like "How do you teach about a. Scientific theory, b. Research procedures, c. Data collection and analysis, d. Objectivity and e. Cutting-edge scientific research." When asked about their teaching and data collection procedures, some responded by

listing various tools and instrumentation used in their classrooms, while others discussed their teaching styles and strategies. Questions yielded such unclear responses that it became increasingly difficult to see how this exercise contributed to the project's overall curriculum development goal. However, his status as curriculum expert enabled him to legitimately pursue his research agenda.

Brainstorming sessions were also good ways of seeing how authority figures were able to successfully pursue their own interests and agendas. As I noted earlier, toward the end of the first workshop, where teachers and scientists were separated into two groups to brainstorm about "practical things that could come out of the project," instead of formulating "practical things," scientists discussed concerns that they felt would negatively affect their Fisher Group's research agenda. First, they felt that the quick graduate student turnover (Terrence graduating in May 2003 and Rachel in May 2004), required that some mechanism be put in place to train new people if they wanted the project to go beyond the life of the scientists currently involved. Second, time was a major concern. As James said:

...I am here to get a Ph.D. and I think we'll have a lot of fun and we'll learn a lot and everybody will benefit a lot from it but I gonna have to remember that there's going to be times where well I could make this a little bit better but I really should be working on my research.

Taking nanotechnology into high schools depended on scientists' ability to negotiate what was important to their research agenda. As teachers were not knowledgeable about nanotechnology, they had to depend on scientists' knowledge and time: how much time and effort scientists were willing to spend in the project. Teachers were very aware of how much they needed scientists to fulfill their tasks as expressed in the following comment made by Anthony:

...they have graduate work that they need to be doing and you know, this is probably won't, it ties into their research a little bit but not much, he can do his dissertation without seeing us period and their research is not dealing with the educational component, [it's] dealing with nanoscience.

Thus, success of the project depended heavily on how much the scientists could really do, what they wanted to do and what they could not do.

Enrolment Strategies

Enrolling and mobilizing actors involve rallying supporters around one's claims. Actors may employ a host of enrolment strategies to persuade others to join the network. In the NCDP, scientists utilized two major strategies: lectures/presentations and laboratory experience to enrol and mobilize teachers.

Lectures and Presentations

Through these strategies, teachers were supposed to learn about nanotechnology, the "tools of the trade" and nanotechnology's potential to address environmental issues in Geosciences. However, lectures are not always effective ways of drawing supporters to accept one's claims, and they can have varying effects on different actors. In NCDP, scientists encountered two problems with this method: first, the amount of information presented and second, the manner in which it was presented.

The first day consisted of eight (8) thirty to forty-five minute (30-45) formal presentations of scientific content by scientists. Teachers confided in a 2002 post workshop focus group interview that they were overwhelmed that first day. Anthony stated:

My first impression like what are they, what are they talking about with those presentations that they gave us. They tried to break it down enough but you have to really be sort of trained in that stuff to really understand the umm, the complexities of it. And, we're not trained in it. I have a little understanding given my background but it's so technical and I've been out of the game for so long that I can't really remember.

During lectures, I observed teachers yawning, nodding off and occasionally closing their eyes. As Charles later acknowledged, it felt like they were “drinking straight from the fire hose.” Kate even remarked that by the end of the seventh (7th) lecture, she was “saturated.” Reflecting on this comment in a post workshop interview, scientists felt that if they had to do it over again, they would “change the overload of information that [they] didn’t make relevant to [teachers’] lives or their teaching”:

I know for myself trying to get at that level was the big challenge. And sometimes I think I was at the proper level and sometimes I think it just blew right by them... I think Melissa’s presentation was the perfect level, as far as presenting your research... I went in and I describe specific experiments and results and James talks about a specific technique and Rachel a little. But Melissa’s was overview: this is why it’s important, why do we care, why should we spend tax dollars researching this, here are the problems we solve.

Yeah, so maybe we could cut out some of the real specifics of it and focus more on other things and let there be more hands-on activities and still keep it within the same time... Take out information that doesn’t need to be presented.

I could have given a ten minute talk on why electron transfer reactions are important in the environment and how, and relate that to nanoscale. That’s not what I did and that’s what I, I mean they don’t need to know any specifics about what I’m going to be doing. So, I could have used. You know, if I just would have done that I mean that would have made a huge difference.

Lectures were generally limited in scope to scientists’ own research field. As Sam noted in a 2003 post workshop interview:

...I have been thinking about this and the point is that what we are talking about over here is only the geo-chemistry or the environmental geology applications. What about the electronic applications? What about the biological applications? What about the physics, chemistry applications? We didn’t talk about that... That the particle size, transport experiment..., that was totally a geological or environmental geological application. Okay, now we didn’t introduce them to like carbon nanotubes or micro-electronic devices or things, other things that are going on, like I have an example, I wanted to show you this... These are the possible applications in the environmental sector. I mean those are only the applications in the environmental sector. What about the huge other applications? We didn’t show them.

In most cases, lectures wholly covered individual scientists’ work without drawing practical connections to curriculum development for high schools. They lacked serious

consideration of high school students as the final consumer. As Charles rightly expressed below, nanotechnology's multidisciplinary nature led to scientists' struggles to find the "right" rhetoric – an important device in building and expanding networks as it helps convince new actors to accept claims and join:

...It draws from a lot of different areas so even translating down to a high school level, it is a big challenge in terms of how can you explain these concepts, how can you give the significance, we can't teach you all the math and all the science you need to truly understand them at the level that a Ph.D. scientist does so how do you translate that down, so that you can understand the concepts without having to get into the gory math for example. And that's really the challenge.

This challenge was most apparent in mathematics (math). From the beginning, it was difficult to determine exactly how nanotechnology could be incorporated into math curriculum. Trying to decipher the possible math applications for her students, Anna posed this question to one of the scientist: "if you were a high school teacher how would you present this so that it would encourage students to do nanoscience"? His response and the discussion that followed revealed that scientists themselves were unsure of exactly how that could be done:

Tell students to look back at old Star Trek/Wars movies. They would probably laugh about it and say "No, you can't do that" but now, we're doing things like this." For example, the Department of Defense has an interest in treating battlefield wounds. They are trying to develop new bandages that when you put it on a wound, it will interact with the tissue to stop the blood flow. They are also looking at designing new uniforms that would keep you more comfortable and drier. There is the ability to do a lot of things we do in science fiction.

Instead of coming up with concrete ways that Math could be taught in the classroom, they continued to list practical applications on nanotechnology. In the end, when I asked her how she might use what she learned in her classroom, Anna confided: "at this point, I cannot see it."

While the relevance of nanotechnology for the other subject areas seemed more obvious, scientists' and project directors' failure to make connections in Math alienated

Anna. During the second workshop, she came only once during an afternoon session, and by the end of the workshop, some participants like Anthony and Daniel conceded that she had not really contributed to the lesson plans. According to Anthony, he did not “really see a Math part right now...that’s because, I don’t remember that lady really showing up in this summer.” Admitting that she too had been uncertain about the Math application from the start, Stacy felt differently about Anna’s contribution:

I think she got the Math all lined up and last year I was a little uncertain about her. And I was certainly uncertain through this year because I didn’t hear from her and I just finally sort of gave up. And at the end, I thought I well, I’ll give, I’ll try her one more time. And I think she really seems energetic and I’m pleased that she’s there. I think she contributed.

However, as Anthony stated, while they were able to integrate some Math into the lesson plans, there wasn’t “a specific Math plan...It’s more so physics, biology, chemistry,” and based on the way the lessons were being developed, he did not see Anna doing nanotechnology in her Math classes:

Nope...she would have to develop her own, you know, it would have to be like a cross-curriculum type thing, or she doing it with somebody in her school.

This was a significant conflict in the NCDP since the NSF goal emphasized curriculum development in both secondary science and math high school classes. The heavy emphasis on Geosciences made it impossible to “do math.” These lectures proved ineffective in pulling Anna in and therefore, ineffective in enrolling her math students into the network.

In the second year, scientists reframed their presentations to make them more relevant, thereby gaining more participation from the teachers. Three (3) sessions were designated for fifteen (15) minute “nano-moments” or lectures. These “nano-moments” updated participants on scientists’ research, and were well received by participants,

especially by Jenna, newcomer to the workshop who said in a 2003 post workshop interview:

...it was better than what I was expecting. First of all, I thought it was very valuable and really important that on one of the days in the summer that the graduate students and some of the professors talked a little bit about what their research was about. And I thought that was huge, I mean I thought that, that's not happened before when I worked on a project, where the scientists have talked about what they do. And I guess, that's really important to me to know what they actually do with this nanotechnology...they were wonderful. It was very nice for me to hear what everybody had to say because the science part of it – the graduate student presentations – most of that I was not familiar with and they did a wonderful job, I thought of presenting their research. I was very impressed with how they spoke to their audience about what they did...

There were also two (2) lengthier presentations on curriculum topics conducted by guest speakers from the Department of Teaching and Learning. The first speaker was a black female professor who discussed issues of diversity and race in the classroom, and the second was a white male Ph.D. candidate who dealt with access and equity in Biotechnology high school curriculum. Of the two lectures although they felt that the diversity talk was “necessary,” participants failed to see its usefulness for developing nanotechnology lesson plans as expressed in the following comments from Sam and Rachel:

...I think definitely they were necessary but the manner in which or the effectiveness or the focus could have been changed a little bit. Like, there was what this person's name who gave the [second] lecture. I liked it...I was happy with his presentation. I was pretty much happy with it because he showed us some examples of what he was talking about, but the other presentation, I was not happy.

I think we needed to do those. I'm not sure that the people who gave the presentations understood what their focus was supposed to be. And, then I'm not sure they efficiently moved in the direction that they needed to move. But, I don't know if that was a lack of communication or what it was...it would have been nice if it had been clearer about what they were trying to say.

The overall problem or conflict with these presentations was two fold. First, some teachers felt that as they had many years of teaching experience and exposure to

such issues as diversity and equity in their own classrooms, the lectures were redundant. Interestingly, over the course of the two (2) years, at no point were teachers given the opportunity to do formal presentations, particularly curriculum development. Their contributions were usually solicited through collaborative discussions or brainstorming sessions. This reflected an uneven distribution of power. Second, as the lectures were not very focused, they could have spent the time working on lesson plans – a problem best exemplified in the following comment by one of the teachers, Kate:

What [the second speaker] had to say, it was kinda like I almost already knew...So, I didn't know if that was for the scientist benefit or was for our benefit but like I say, it was nice to know what he was doing, what approaches he was taking to teaching and that type of thing...But, I think that we need that time working. Also, with [the first speaker], I was a little bit restless with that...That I already know and I know the cultural differences because I worked with a man from India on the CD-rom project and his customs and their whole way of thinking...are totally different...I guess I just felt like, being a woman, I know quite a bit about diversity, I know a little bit about prejudices and I know a little bit about things like that...and I guess, you know, that's what, I guess I couldn't see the transference from cultural differences to nanotechnology...how that was gonna come over to my classroom. How it was gonna be different. You know, but if you gonna do, if you gonna do a lab, you're gonna say this is the lab, this is why we're gonna do it, let's go do it. And, you know not say, okay because you're from here, you're gonna do it this way, and if you're from, this, this, you know what I mean, so that's what I guess I'm saying, I didn't see the correlation. I didn't see the correlation the diversity and the product that we were trying to do...So, to me I guess you know and I appreciate her time, and I appreciate her coming and talking about it but I guess I saw that as time we should be, we needed to be working on that. I guess I'm thinking I wouldn't have to stay til 5:30 or quarter to 6 if we'd have had that time.

Scientists also felt that speakers should have been given more direction in planning and focusing their presentation to apply to the workshop. For example, James adamantly indicated,

...if we're going to have a guest speaker, we should know ahead of time what they need, and where we should be and so that, we come in, we start when we're supposed to start and when they're finished, then we can go to work right away instead of taking a whole morning...the diversity seminar. I thought it was very appropriate and it's something that unless you bring it to the forefront that people aren't gonna necessarily think about it as much as they should. But, on the other hand, I think asking someone to do something at the last minute but they're not

prepared for what audience they're gonna be speaking is not necessarily the best, most effective use of everyone's time either... It seemed like it was more like this is the talk that I give and I'm gonna come and give it to you.

Lab Experience

In the first planning meeting in 2002, when teachers were asked what sort of things they might want to take into their classrooms, although unsure of their expectations, all expressed a desire to be able to go into the laboratory and work with scientists' tools. To better familiarize teachers with the practical aspects of nanotechnology, scientists engaged teachers in the second enrolment strategy: hands-on laboratory experience. For example, at the end of the first day during the first workshop, teachers were given lab instruments to conduct a halite precipitation experiment. The objective of the experiment was to obtain halite crystals that could be observed under the microscopes in the next day's laboratory activities.

On the second day, participants were separated into two groups and taken to the two laboratories – the Mineral Surface Geochemistry (MSG) and the Hancock Labs to use their halite crystal samples to generate data. Due to limited space in the MSG lab, these activities were conducted on a rotating basis with some participants using the Hancock Lab in the morning as others used the MSG lab. In the afternoon, the two groups switched. The labs were intended to allow everyone to spend time working on and familiarizing themselves with the instruments and to examine their samples using several different techniques.

In the Atomic Force Microscopy (AFM) lab session, teachers got the opportunity to look at samples through a regular microscope called a stereoscope. Having years of experience and expertise using this equipment in their own science classes, teachers were not particularly impressed by what they saw. However, as they moved to a higher

powered optical microscope, which began to reveal more of the cubic structure of the sample, they became very excited, frequently referring to their observations as “cool” or “real cool.”

One of the teachers was given the “very difficult and tedious” task of attaching a tip to a cantilever. Once this was accomplished, teachers took turns looking at it through the stereoscope and the optical microscope. The attachment with the crystal sample was then placed in the AFM, which was hooked up to a video camera and two computers. The video camera enabled teachers to “capture” AFM images that were transmitted to a television set. From the computers, they collected data on force measurements of their samples and “manipulated” data to make changes, either an increase or decrease, in force measurements. They saw sweep diagrams on the frequency of movements or vibrations as changes were made to the data. Teachers were very excited and some verbally expressed a deeper appreciation for how scientists do nanotechnology.

When the groups switched in the afternoon, under supervision of a male lab technician, teachers were given a tour of the Hancock lab and its instruments, and the opportunity to see him prepare a sample of a spider for the Scanning Electron Microscopy (SEM). The first step was to coat the insect with gold plasma at least six (6) nanometers thick. As the coating was applied, the spider began to change to a purple color, indicating that the gold was penetrating into the insect. Teachers became very excited about these changes. Next, they were shown the SEM. Once the sample coating was completed and mounted to the SEM, everyone took turns viewing the surface structure of the spider and using the joystick to play with the sample. Teachers then saw images of their crystal samples that were transmitted to a computer program in order to

produce a “quick quantitative analysis” or what James referred to as “semi-quantitative results” involving charts and graphs that show the actual chemical composition of the structure.

Although these lab experiences served as more effective enrolment strategies in mobilizing the teachers than the lectures and presentations, scientists encountered problems. Too little time was allocated during the first workshop for teachers to absorb the wealth of lab information they received, as Terrence said in a 2002 post workshop focus group interview:

I think at times it was a little intense. I know that especially on the lab day, when the groups split up by the time I got the afternoon group, they were exhausted and I think James would agree with that. You know, by the time, I mean so maybe two labs in one day was, could have been split up a little bit more. So, that was intense.

Teachers’ expectations of spending a lot of time in the laboratory were not realized, and at the end of the first workshop, Kate openly expressed her disappointment at not having had the opportunity to “actually see some mineral-microbe interaction.” These problems led scientists to renegotiate and reframe their strategies in the second workshop.

Teachers and scientists spent significantly more time working in the MSG laboratory testing curriculum ideas:

...They’re coming out thinking AFM because they’ve used it, they’ve seen it. They’re coming out thinking SEM because they’ve seen it, they’ve used it. But they’re not retaining a lot of information about bioremediation, for example, that definitely we’ve seen that this activity driven learning is much more effective than lecturing...I think that that was epitomized by what Kate said, she, you know, even though we all talked about microbe mineral interactions, she was like: that’s fine, that’s great. I want to see it.

One thing I like about this time that we’ve had is that we were actually in the lab experimenting and trying to come up with ways of doing this and this didn’t work, so we had to do a different way and, we were thinking when we started out we’re going down one path and that’s how we’re gonna do the lab. And we’re thinking this is what’s gonna come out of it and then we completely changed it around because we got in the lab and we actually you know working with the

scientists and changing methods and you know how we were going to do the lab and that type of thing. So, to me, I, I really enjoyed, being in the lab and actually doing the lab. I guess maybe the past two days, at least one day, we've spent totally in the lab and then two half days experimenting and coming up with procedures and how to solve problems and that I really enjoyed that.

Labor Distribution

In the second year, to accomplish the task of developing curriculum, project directors decided to separate participants into two work groups; each consisting of some teachers, graduate students and faculty. In Group One, there was the curriculum expert (Gary), two graduate student scientists (James and Sam), the Chemistry teacher (Jenna), the Physics teacher (Megan) and the Biology teacher (Daniel). Group Two consisted of the outreach director (Stacy), a faculty scientist (Melissa), a graduate student scientist (Rachel), the Earth Sciences teacher (Kate), the Chemistry teacher (Anthony), and the Math teacher (Anna who only participated once that year).

Ideally, division into groups helps to achieve efficiency but for the NCDP, dividing into work groups resulted in conflict. First, one of the pitfalls was the leadership. Russell and Flynn (1992: 12) have pointed out that a collaborative endeavor “needs to have direction...the members must know why they are there and have a clear sense of what they would like to accomplish.” In the NCDP, the leadership in one work group seemed weaker than the other. For instance, when groups separated to finalize specific curricula themes for lesson plans, Group Two quickly identified several themes: “Environmental Pollutants” which focused on ground water, acid mine drainage, mineral dust, role of bacteria; “Rock Cycle” which emphasized the role of microbes, sustainable earth, global warming, earth system, soil erosion and the quality of oceans; and “Ethics.” They used Gary’s sample of the 5-E Learning Model to develop practical activities – case

studies, role-playing, KWL charts, pictures and websites – to teach nanotechnology to high school students.

However the lack of direction from the project director in Group One resulted in an entirely different focus. Rather than develop themes, group members proceeded to rehash earlier discussions about problems related to computer access, software compatibility and availability of nanotechnology tools. The project director made little attempts to steer discussions to the specific task of themes for curriculum development. When one teacher directly addressed the topic, asking others if their big idea or contribution to the lesson plans would be to show how things at the nanoscale worked differently, no one responded. This lack of direction and organization in Group One was even more noticeable when at the end of the day, the two work groups met to give their reports. Group Two produced a lesson plan draft on Environmental Pollutants using the 5-E strategy model.

Table 5.1: Environmental Pollutants Lesson Plan Draft

1 st step:	Engage	Have Examples e.g. Erin Brockervich. Use KWL model
2 nd step:	Explore	What is in your own water; show bacteria is everywhere; Take samples at schools, etc. mineral dust collection
3 rd step:	Explain	Why did some stick?
4 th step:	Extend	Look in global areas, go into homes and do samples.
5 th step:	Evaluate	Case study, role playing, submission of reports.

Group One’s contribution was to do a case study on microbe-bacteria interaction – an idea which came to James in the “last 15 minutes” and which had not been discussed

fully with his group members. The problem of weak leadership so bothered another scientist that he later pointed out that his group would have gone on “just fine” without the assigned project director.

Second, although participants were divided into groups to achieve some level of equal distribution so that for each group, teachers, project directors and scientists worked together, in a 2003 post workshop focus group interview, Rachel revealed that the idea of separating participants “before [they] got here was a poor idea because it did not make an equal balance.” Sam also agreed that he did not find the work groups very “constructive”:

What we had for the first 2 days was okay let’s brainstorm, let’s brainstorm, let’s do this, let’s do that. Okay 2 groups go to 2 different places...Then, at the last 2 days everything had to be churned out real, real fast, real fast. So, it was like, to me it was lot more like a very high tech, everything is non-crystallized, then suddenly everything starts to crystallize randomly. Being a student of like Maths and Physics and stuff, I can’t conceive this as ordered. That’s what makes me squeamish.

Teachers also felt that the uneven distribution of labor hampered the goal of developing lesson plans:

...I think breaking up like that, and there was a reason we broke up the way we broke up and we tried to put, there was some diversity in each group, you know chemists, biologists, and a graduate student and geologist...And it was also really difficult for me because I’m not a geologist and I struggled with seeing where the chemistry link would be and where a link would be that would be strong enough that I could use in a high school classroom.

...I think all the teachers were struggling with that cause this is truly an integrated lesson we’ve made and you know I don’t have the Chemistry, you don’t have the Biology and you don’t have the whatever, and it really is a problem that you don’t know all the questions and answers to a lab that you’re writing but someone in the group usually has an idea – might have to ask five people before you get it.

Dissatisfaction with labor distribution was further compounded by fluctuations in attendance. For instance, though Charles participated in the first workshop, before the

second workshop, Steve informed Stacy that Charles would not participate as he would be working on his own research. In his place, a new post doctoral faculty member – Ben would join the project and so, he was assigned to Group Two. However, after presenting one of the nano-moments on the first day, Ben never returned. Instead, Charles kept popping in during work group sessions. This confused Stacy, the outreach director, who noted in a 2003 post workshop interview with me:

...One thing has puzzled me this last year is the role of the post docs. Because [Ben], I had the impression he was all in there and then it turns out he was busy. And then, [Charles] I had the impression he wasn't going to work with us. Steve said Oh, he's on his own thing now, don't worry about him. And then, he showed up...That was difficult for me, and I think for everybody...

It was difficult and created conflict in the groups because, having been absent from earlier discussions and joining group members when they were well into curriculum development, Charles kept asking questions which were already settled. He wanted to know “how do we put things together without using expensive equipment? What types of things can you envision using? Where should nanotechnology fit in? How are we going to teach these things to fit into Chemistry, Physics, Biology”? This created tension and distracted members from their tasks as they tried to answer his questions. On the third day, he did not return because according to another scientist, he may have felt that his ideas were not being considered.

Fluctuations in attendance within the two groups also created conflict because some people were either absent from work sessions or left early to run errands or attend to other personal and professional commitments. According to Rachel:

A lot of people left, and we're just, we're lacking strengths in some groups. It would have been more interesting if we talked about our ideas as an entire group, came up with these two different labs or lesson plans that we wanted to develop and then separated based on interest of that. Because I don't think that the groups are working that well right now...I think that there are some people who are here, but are just distracted. There're too many other things going on, they're

not focused on the workshop and these four days and getting the project done cause there are so many other things going on in their lives, and it makes for unbalanced group work, and it's hard to assemble tasks or distribute tasks to certain people because they've got to get up and go at lunchtime. So, it's been hard to work because of that.

This was particularly distressing for the members in Group Two who felt that their group “wasn't as rich with people and expertise” because its size was significantly decreased by the third day of the second workshop. In a 2003 post workshop interview, Kate complained:

Rachel and I stayed one day til almost like 5:30 working on trying to get the paper together. I think the only thing that I could say about that is that we have these teams and then, especially our team that we were on, the team members had to leave or go do something else or they were gone, and so it kinda left, cause we had to produce this product and so, it kinda left Rachel and me to, to wrap it all up and put it together and type it all up to get it, and that was the only thing I guess that kinda bothered me just a little bit because I thought well, you know, I could say well I've got something to do and I got to leave too and I know, I'm sure that what they had to do is very important but it kinda, you know, it's like our team started out and we had 6 people, then we went down to 5 people, then we went down to 4 people, then, we went down to 2 people and in the other team over here, still has their 6 people. And so, it was kind of like, it was unfair to our team that people had to leave and I know they've got things, but I'm just thinking that you know they should really be able to say okay it's four days, we're gonna work on it four days, we're gonna be there for four days and we're not gonna put this in the lap of our team members to pick up the slack or finish the product or you know, that type of thing. And so, that was the only thing...did just start out with five, but still out of five, six, five or six, it got, basically it just was the two of us working late and trying to get the product together.

In retrospect, the project directors realized that dividing participants into groups was not the most effective way to develop curriculum as Gary remarked:

I don't know how that all happened but... I know that other group had Anthony and Kate and Rachel and they were working very hard to make this experiment happen, which was the core of what they were trying to produce. So, I think the idea of breaking up produced different ideas. I think the downside of that was that we weren't as much on the same page as far as timetable for writing and things like that.

The uneven distribution of expertise resulted in them taking considerable time to come up with drafts and slowed the curriculum development process.

Communication and Feedback

One of the goals of the NCDP was to “establish ongoing communication and partnerships among high school teachers, scientists and faculty at Virginia Tech.” These make up a core element in the growth of a network. As Mullins (1973: 18) pointed out, in addition to coauthorship, apprenticeship and collegueship, communication was an important social relationship in the general scientific structure. Without communicative structures that let actors know what is happening in the network, they may find it disadvantageous to maintain their link to the network. After the first workshop, scientists and project directors created a website with a discussion board to maintain “some ongoing communication” between workshops. Project directors also involved teachers in developing abstracts and attending professional meetings.

However, at the start of the second workshop, another point of conflict within the NCDP surfaced: lack of communication and feedback. Kate said the following:

...I guess it would help to get just to a little bit more communication about, and it wouldn't have to be a long letter. It's like this is, we sent the labs off to such and such, or we send the summary of what we did to NSF or we sent and this is what we sent to so and so. You know, just give you an idea, just little burps maybe about they've done with what we did last summer.

There were no briefings or planning sessions to inform new actors – Sam and Jenna – of the first workshop's activities or the upcoming workshop schedule. This was particularly disheartening for Sam who felt that if there had been a “short course” where individuals who participated in the previous workshop briefed “the newcomers,” he would have had a “clearer perspective of what [was] going on, when it[was] going on and what [was] going to be”:

What I think is, this, this whole outreach program for me, initially was a very new thing. So, I was like just suddenly...oh, okay we have an outreach program so you have to come to the meeting, okay. So, I get a folder, big folder and I

entered nothing. So, I didn't have any briefing. I didn't have any recap of what happened last time. I don't, I didn't have the documents of what they came up with, the things that you guys did...and stuff like that. I only saw the poster. And, being not a scientist actually, a science student I'd say that that was not enough for me. I need to know my parameters. I need to know my constants before I can go into anything. So, that was a very big thing for me. Remember every time I was saying that yes, I don't know this, I'm not comfortable with this, what's going on, what are you talking about, the different type of like standards that you guys have. I didn't know anything...I had come to this workshop for the first time and until and unless I went through the first day or the second day a little bit, I was not exactly clear about what we are trying to do and where is my role and where I fit in... But I think people who are going to join the group next year and who are totally new to this concept, they should be given a small introduction, a small, small section...or people who have already been there, like what we are doing. Not the webpage, not showing the webpage or giving course material, it's better if there is an interactive session before the actual, that would really help.

Lack of communication among scientists was also a problem. For instance, Sam felt that they needed "a little more time to discuss amongst themselves what type of experiments or things that they [were] coming up with":

...we need to talk between ourselves first. And, then brainstorm with the teachers and you guys and then come up with the final thing that we're going to work upon. That didn't happen. What happened was, everybody was sitting in a room and everybody was voicing their suggestions and then, suddenly a thing comes up, somebody goes into a computer room, sits in front of computer and comes up with, cranks out things from the internet. No. I would like a course curriculum to be fundamentally basically solid. So, in order to do that we need to do a lot more I mean background searching, lot more theoretical, to see whether my theory is correct or not. Like, we were saying this can happen or that can happen. Let's ask our expert first. Expert means I don't think I am expert right this, at this point in time, I'm learning. I'm a grad student. So, we should have had Steve more in the meetings...we need to talk amongst ourselves first, the scientists, that these are the things that can be put into there and then in order to simplify it to a level that the kid, well people can understand, that's where the school teachers come in...Because when James came up with something like let's do this AFM draft out of the blue in the meeting, I was caught unawares because we didn't discuss this...What I'm trying to say is let's talk out what is our game plan first, and then let's take it out to everyone, then work it out together...Team work is essential. That's there. What I'm talking about is scientist talk amongst themselves, the educationists talk amongst themselves, what they want and what they can give.

The inability to maintain ongoing communication created conflict in participants' ability to fulfill certain tasks like attending and participating in professional meetings. After the

second workshop, Sam confided that “nobody went to GSA.” [See Appendix F for acronym]. Although he intended on participating, his attempts to reach one of the project directors via email to begin outlining an abstract were to no avail: “I couldn’t get any feedback.” James, another scientist, also expressed his disappointment in a 2003 post workshop focus group interview at the low turnout by teachers to professional meetings:

...I was really (with emphasis) disappointed the first time I showed up at the VAST (pounding his fist on desk), and none of them were there, and it wasn’t because they didn’t necessarily want to come, it was because they weren’t asked to come (speaking in low tones). So, to me that was a real let down and I think that sort of got, and then, the other, I was at one other conference and also was Stacy, Gary and I and then this other guy from Northern Virginia...once again, I felt like if it was gonna be about the teachers which it should be mostly that maybe we could do a better job of making that happen.

There were those who were able to keep the lines of communication going, particularly within individual work groups. During the six months following the second workshop, in an interview with Jenna, she indicated that she continued to consult with graduate student scientists via email. Gary, Anthony, Jenna, Daniel and James also worked together to present a paper at a professional meeting in the Fall of 2003. Speaking of this experience, Anthony noted that despite the increased because “the teachers [understood] the project a lot better,” he still felt lost. Since attending the Fall 2003 meeting, he had not received any feedback on what was expected of him for the next workshop:

Outside of that, I know I would like to know where do we go from here. I still don’t have a clear conception of what are we doing next, and what’s the next phase of the project. Well, what do we have to do, I’m still confused on that. You know are we just to develop more lesson plans or are we to you know? I don’t know what’s next, maybe they said it and I missed it but I don’t think. Well, I know they’re supposed to test our, the teachers are gonna test some of the labs and stuff and I’m saying like what is the next phase of the project. I mean what is required of us now.

Project directors failed to communicate and provide adequate feedback during the year between workshops. Admitting that this was a “valid criticism” of the project, Gary was hopeful that they might be able to rectify the problem before the 2004 workshop. Yet, by the Spring of 2004, communication and feedback among participants was minimal. As Sam asserted:

Feedback – bad, bad, we don’t even know what’s going on, I don’t what going on. I only suddenly see James coming up with this webpage or he’s coming up with the finalized version of the AFM material...Feedback, follow through, not good, not good.

Later, in an interview with Kate, she indicated that she was still waiting for a copy of the nano poster used during the 2003 workshop. She also hoped that before the third workshop, she would have been given “something... even if it is just a summary of what was done, where it was sent, if something was actually sent, sent to the National Science Foundation or a copy of what was sent...just a summary, it wouldn’t have to be a full page, just a half a page just to say up-to-date, this is what’s happening, this is what’s been done and this is what we’re gonna do.”

Gender and Race

Actor network theorists have often been criticized for ignoring social factors like gender and race and their effects on scientific network. These factors were important in this case study. In particular, gender issues in the NCDP revealed power differentials in which some female participants, despite their knowledge, were treated in secondary statuses. For example, both project directors occupied high level positions and because Stacy was the main project director, she had a more dominant role than Gary. However, I frequently observed that she performed the brunt of the administrative tasks over the two years.

Sociologists have consistently shed light on such inequalities that exist between men and women such as the gendered division of labor in science (Bleier 1986; Byrne 1993; Ellis 2003; Pattatucci 1998; Thom 2001; Rossiter 1993; Ginther 2003; Sonnert and Holton 1995). For example, Zuckerman (1991) found persisting differences between men and women scientists in role performance, in access to resources, in research performance and rewards and in published productivity. Women are disadvantaged from men in rank, salary, research performance and reputation. Eisenhart and Finkel (1998) also point out that although there was a marked growth in the representation of women in science during the late 70's and early 80's, women still lag behind men in science and engineering professions and primarily inhabit lower-status positions (Schiebinger 1987).

Historically, in the Geosciences field, “gentleman” scientists – wealthy elite men who were independent scholars – played a greater role in its development as compared with many other fields (Schofer 2003; Porter 1978; Rudwick 1985). We already saw that a pattern of low female representation in the Geosciences Department at Virginia Tech exists. This inequality between the sexes is explicitly demonstrated in the official workshop meeting place – the Geosciences conference room on the fourth floor of Derring Hall. Feminists have adequately drawn our attention to the sexual politics of space and so I will not go into a lengthy discussion here, except to note that space can be gendered. This was the case with the NCDP space.

In the conference room, along one wall is a row of frames containing photos of fourteen (14) past chairs of the Geosciences Department – all tenured white male professors. If Wajcman's (1991) assertion that the built environment reflects and reinforces an ideal which emphasizes gender roles is correct, then these photos represent

visual symbols of patriarchal relations within the Department. They give concrete expression to the unequal relations between men and women and they say: men have the power here! Initially a few participants made knowing glances and nods at the photos and Stacy, the female project director, cynically remarked that it was “highly unlikely if a female would eventually grace the walls.”

Although the female scientists were already acclimated to the male-dominated environment in Geosciences, they were very aware of their status as “second class citizens” in the Department. For example, of the two hydrogeologists in the Department, Melissa was the only female and admitted that though the challenge of being a female in a male dominated science is not as much as it was, perhaps ten, twenty, thirty years ago, it was still a challenge: “I think there’s still expectations that women should be a certain way or do a certain thing and it’s hard to necessarily contradict those or to do something differently.” Stacy, though her role as the outreach project director afforded a higher status and authority, recognized her minority status as a female in the Department:

I think science has been the purview of white males and science is constructed with a very Western white male construct. So, if we’re gonna really get at more interesting answers and more broad questions and what can science be, we’ve got to be inclusive and that we have to teach that way, we have to have many types of peoples...

With this recognition, she developed a keen interest in having research goals that included the feminist critique of science: “I read a lot about and I always have my eye for that.....science is not just this, it can’t be all white men going toward the truth, you know. We need different perspectives to make better science...”

As she was the only female graduate student scientist, Rachel also felt that a sense of responsibility to accurately represent women in science. Since the first workshop began with three female high school teachers and two male teachers, in Rachel’s opinion,

it was “good for the female teachers to see that women are applying this and maybe mention that in their classrooms even as a passing: she did this. It’s always good to introduce science to female high school students.”

In as much as women represent a disadvantaged group, their roles and positions in the workshops reflected power differentials that led to conflict. This was observed during the first workshop where Rachel became upset that her input and comments were being dismissed by a male scientist. She felt that because she was a woman, he seemed to think all her answers were wrong, “but when, he rewords them with the exact same concept, voila, they suddenly become right.” This gender conflict did not extend to the female teachers. They were already conscious of gender inequality existing in Geosciences as Kate made a point of describing how she was discouraged from pursuing Geology when she first joined the Geosciences Department: “When I was at Tech and somebody said, oh you know maybe you ought to think about going into teaching and not being a geologist because you’re a woman, you’re not getting a job.”

Historically, science has also excluded blacks and other minorities and their inclusion has often been in the capacity as “tokens” (Harding 1993). In the NCDP, there was only one African American male who was very aware of his position as a black man in a predominately white male world, and as a minority in the project. He felt a certain sense of affinity to me (as I am also black) and in informal conversations often indicated that it was difficult to be in the sciences. The racial divide was in part responsible for his decision to switch his major from chemistry to science education:

[It]was a better environment for me to thrive in and be successful. Diversity is really, really needed in the hard sciences such as chemistry, biology, physics departments and this university. They’re trying to understand how, you know, how people operate within the system that they have created and how it’s

oppressive but you know at the same time, they can do, they can have some changes over there...

Although he was not treated differently by anyone in the project, race was an important issue for him as he mentioned in our informal conversations that he felt he always had to prove himself.

The race issue came to the forefront during a lecture on diversity conducted by a black female professor from the Department of Teaching and Learning. In her talk, she discussed definitions of diversity, hidden messages in high school curriculum and how cultural differences in science, particularly “the male-dominated culture of science,” influence scientific content and practice. Adopting a social constructivist perspective, she explained that one could not separate the idea of diversity from stereotyping, that is, images and labels about others: “There are no neutral parties – nowhere!”

Participants then entered into a lengthy discussion about the connection between diversity and science curriculum, where scientists had difficulty in understanding race and gender issues affected science. As one male scientist flatly stated “I don’t see it.” Daniel, one of the two male teachers also expressed to me that he could not see the relevance of race and gender to nanotechnology. On the other hand, when I asked Anthony how he felt about the lecture and discussion, he stated:

I’m one of the oppressed people here so. Maybe it helped some of the Europeans but ah, I remember one, the scientist, he was a little, I think he had this idea that science is completely objective and this, that and the other. And it doesn’t really oppress, but we know that to be false, because the whole system as it is oppresses and marginalizes certain groups of people but if anything, I don’t know if he got anything from it. Me, myself I just enjoy listening to it myself. Yes, it’s worth bringing out and that’s the only way change will come about but at the same time, it’s a little scary. Because like when they asked me to speak on my research topic which is you know, at that time it was African-American men but now how the system seems to, the by-products of a system of oppression is what you have now and that’s why we have so, such low representation in the Math and Sciences in African-Americans because that’s what this system was designed to do. But, to say, tell that to a group of European Americans who are not versed

in, say the social sciences or they're just pure sciences you know, they might like, that's a bunch of baloney, so, it's hard that way, but it's needed...

Financial Compensation

Conflict can involve equity issues such as the distribution of rewards (Kabanoff 1991). Of the \$1.1 million dollars requested, approximately \$150,000 (13.6%) was proposed for use in the outreach project. In the NCDP, teachers were paid approximately five hundred dollars (\$500), including travel and food expenses for each workshop they attended. Project directors received significantly more compensation [approximately ten (10) times] than high school teachers.

Hall (1998: 123) states that “the nature of the incentive system within the organization is an important power consideration.” The distribution of money in the NCDP reflected the unequal distribution of power and status among participants. While teachers' salaries remained constant throughout the project, those in higher positions received increases every year. Though teachers were unaware of the disparities and some felt the stipend was “fair,” others expressed that for the amount of work involved, it was not “really that much after taxes” and should be increased as Anthony said:

“we get paid every summer which is not enough but it's alright for a week of work, which is a little less than what I'm usually making but and then all the stuff you have to do through the year and meet, the five hundred every year is really not anything but it averages the minimum wage...

He also confided in a 2003 post workshop interview that he overheard “one person saying that the five hundred dollars is running thin. You know even though I get reimbursed for gas and stuff, that's like, that's time.”

The money conflict was particularly important in light of the fact that teachers were expected to return for two days in the month of August to refine lesson plans and test their experiments; for which they received no financial compensation beyond travel

expenses. Some did not attend and some felt that they should have been compensated for that time as verbalized by one of the teachers in the following statement:

...Again, I must say that I think [we] deserve more money. Umm, it's like 500 dollars like for the summer, but you're here for a week, that's what you'd, you would make at a job anyway but when we have meetings planned throughout the year and stuff, and teachers have to come here and give their time without any type of compensation, you know, coming once is okay but you know like we had maybe two or three, four meetings since the summer, and you know, you're expected to be here, you want to be here and you don't want to, you want to do your part but at the same time...maybe in the fall, if they meet two or three times, maybe give them maybe 200 dollars in the spring, if they meet two or three times, maybe give them 200 dollars or something like that...outside the issue of more money period. You could put that down like four or five times...that five hundred you had in the summer that's, that's gone and you worked and you earned that five hundred dollars but you know, if you come in here two, three, four, five, six times during the semester, you know, that's, that's time.

Project directors were informed that high school teachers wanted a raise in their stipends.

Stacy felt that the amount given was “not insignificant, that's more pay than the three, four days” they worked.

Summary and Conclusions

In this Chapter, I presented several factors within the NCDP that affected the nanotechnology network: decision making and control, personal interests and agendas, enrolment strategies, labor distribution, communication and feedback, gender and race, and financial compensation. These “internal struggles” showed that the network can be a site for asymmetric power relations, which can lead to conflict. Conflict ultimately affects the configuration of the network by placing strain on actors' ability to mobilize others into the network and thereby, expanding it.

In the NCDP, those in the authority positions had more power and control over decision-making processes than others. This case study showed that project directors and scientists made most of the important decisions relating to workshop agenda, activities, objectives, presentations, curriculum themes, pedagogy and models for curriculum

development. Teachers had little control over basic goals, parameters, practices and resources. Because project directors and scientists were in the “power” positions, and because teachers were dependent on them for access to knowledge and equipment, project directors and scientists were able to use their authority to redefine their roles based on their own interests and to decide what aspects of nanotechnology to promote in keeping with their own interests, thereby restricting teachers’ enrolment in the network to their specific research interests, ideologies and perspectives in Earth Sciences. This created tension in the network and ultimately the alienation of one set of actors – the Math teacher and ultimately her students – from the network.

The case study also revealed that interactions between actors are not always uni-directional with those in power positions having the advantage over those in subordinate positions. Consistent with the notion that the network is a “seamless web” where all actors are interdependent, I found that teachers were also powerful agents in determining the successful growth of the network. They brought “practicality” – a necessary component in effective collaboration as Trubowitz and Longo (1997: 33) found that a primary weakness of college staff was their “naïve assumptions about what can be done in the school setting and how change can be brought about” because they were not part of the school culture. As Gary noted, “if a scientist says let’s try such and such, they’ll go why, what purpose is it. [the teachers] will bring the reality of what it’s like to teach.” Therefore, the teachers acted as critical monitoring nodes filtering out what they felt was unnecessary or impractical for high school students and embracing ideas that coincided with the realities of school culture. This reveals that building and expanding networks involves constant negotiation among actors and their interests.

As I explained in the previous Chapter, actors had several interests and agendas – both personal and professional. In this case study, those in the authority positions tried to pursue their own research interests and agendas. The effect of this on network building and expansion was loss of time spent on curriculum development. Although this did not adversely affect the NCDP, it did have the potential to decrease the size of the network: if participants, in pursuing their own agendas, were unable to fulfill project goals in the allotted time, then they would fail to enrol high school students – the final consumer – and other supporters to nanotechnology claims.

This case study showed that enrolment strategies like presentations and laboratory experience were important to expanding the nanotechnology network. Through lectures, scientists and project directors persuaded teachers to accept nanotechnology claims. Then, as teachers got to touch and use the instruments as well as see organisms at the nanoscale, they became more convinced of scientists' work. They wanted to continue their enrolment and stay connected to the network. Ineffective use of enrolment strategies led project directors and scientists to “phase out” elements that were not well received and to constantly reframe their strategies so that teachers could accept claims and join the network. This not only revealed network building as a complex process, it also showed that finding the “right” rhetoric and persuasion tools are key.

This case study also showed that expanding scientific networks is not inevitable. In other words, simply making claims about nanotechnology does not mean that actors will automatically become mobilized. The labor distribution patterns of the NCDP showed that it required good leadership – actors who are able to provide direction and stability in the network. Lack of direction had the potential to displace actors already

enrolled and to provide the basis for actors exiting the network. For actors, particularly those separated by spatial distance, to continue their enrolment in the network, there must also be effective systems of communication and feedback. In the NCDP, lack of communication and feedback led to a sense of alienation, particularly among teachers, thus revealing that even with the goal of curriculum development, having common interests is sometimes not sufficient to keep actors linked to the network.

In the NCDP, gender and race issues affected the configuration of the network. It revealed that hierarchies exist within networks; a concept that has received little or no attention from actor network theorists. Such hierarchies reflect the presence of inequality. Gender and race inequalities can affect the network because they provide the bases for some actors to be excluded from the network altogether, discouraging their participation and thereby, decreasing the size of the network. When actors do remain in the network, gender and race inequalities can create conflict, which may lead to the destabilization of the network because actors already enrolled may become disenfranchised and exit the network. In the NCDP, while the female scientists' awareness of their secondary roles led to discontent for some, gender inequality led others to a firmer resolve to consciously enrol in the network. Gender and race therefore provided the grounds for their link to the network.

Finally, inequalities in the financial compensation patterns in the NCDP also had the potential to affect the network. Like gender and race issues, the uneven distribution of money revealed power, hierarchies and existing inequalities among actors. This had the potential to decrease the size of the network if those being paid less (the teachers) decided to resist and terminate their enrolment in the network.

¹ According to Lorschach (2003), the 5-E Learning Cycle Model is an established planning method in science education and consistent with contemporary theories about how individuals learn. It consists of five parts which are not discrete or linear: 1. Engage – in this stage, you want to create interest and generate curiosity in the topic of study; raise questions and elicit response from students that will give you an idea of what they already know; 2. Explore – Students should be given opportunities to work together without direct instruction from the teacher. They can test predictions and hypotheses and/or form new ones, try alternatives and discuss them with peers, record observations and ideas and suspend judgment; 3. Explain – Encourage students to explain concepts in their own words, ask for evidence and clarification of their explanation, listen critically to one another’s explanation and those of the teacher; 4. Extend – Students should apply concepts and skills in new (but similar) situations and use formal labels and definitions; and 5. Evaluate – Evaluation should take place throughout the learning experience. Observe students’ knowledge and/or skills, application of new concepts and a change in thinking.

Chapter Six : DECONSTRUCTING THE NETWORK, PART II EXTERNAL ISSUES

In Chapter Five I looked at the “internal struggles” in the Nanotechnology Curriculum Development Project (NCDP) that affected the network. In this Chapter, I explore the notion that group behavior is influenced by events and conditions existing in the larger environment: the dynamics taking place in a group is a function of the interactions and associations between the group or its members and the environment. Specifically, I address the following research question:

- What external factors affected the network?

Consistent with the political economy approach to the study of groups, this Chapter is based on the premise that all groups exist within a political and economic context – a social environment – that impinges on them, and can be a source of strain or conflict.

More precisely, actor network theorists like Callon (1986: 30) posit that “an entity in an actor-world only exists in context, that is, in the juxtaposition with other entities to which it is linked.” This implies two things. First, nodes do not exist within a vacuum and second, since a network is a web of interrelated parts, nodes affect each other. These implications hold true for all groups: they are not simply collections of individuals, but are systems in which members are interdependent, and because of this interdependence, conflict is always present.

This is especially true for the nanotechnology network under investigation, as Merton (1973: 278) indicates that conflict becomes accentuated whenever science extends its research to new areas. Over the two year period, in my pre and post workshop interviews with project directors and scientists in the Fisher Group, I found that they

identified several sources of strain or, in Hughes' terminology, "reverse salients" that could adversely affect the entire nanotechnology network – "strong interdisciplinary science background," "a lot of interdisciplinary scientists working together," "efficient allocation of resources," "government regulation," "public perception," "vision," "time," "education" and "money" or "funding." As it pertains to this study, I first identify and describe the three external factors or sources of conflict in the NCDP: university research agenda, dissemination and publicity, and Standards of Learning (SOL). Then, I concluded by explaining how these external factors affected or had the potential to affect the nanotechnology network.

University Research Agenda

According to (Byrd 1993: 6), "higher education has an enormous stake in the product of our elementary and secondary schools. There must be constant interaction between the schools and higher education if the crisis in public education is to be solved." Therefore, one constant in discussions of teacher education and school reform over the past two decades has been the demand for school/university partnership. In 1985, the U.S. National Commission for Excellence in Teacher Education called for the connections between colleges and schools to be significantly improved.

A year later, the Carnegie Forum (1986: 76) recommended that the establishment of clinical schools, "outstanding public schools working closely with schools of education," be formed. The Holmes Group (1986: 67) endorsed school/university partnerships in the form of Professional Development Schools that would demonstrate "reciprocity, or mutual exchange and benefit between research and practice." Other reformers recommended increased attention to the collegial relations of teachers in

professional development initiatives (Lieberman 1995; Little 1993), proposing that such initiatives “be collaborative, involving a sharing of knowledge among educators and a focus on teachers’ communities of practice rather than on individual teachers” (Darling-Hammond and McLaughlin 1995: 598).

Although the nature of school/university collaboration remains ill-defined, it has become one of the buzz words in education and numerous collaborative efforts have been mounted. Mainly what seems to define a collaborative effort is the attempt to bring in support and know-how from sources outside of the normal boundaries of the school as an institution. However, as Trubowitz and Longo (1997) point out, there are factors of difference between schools and universities like differences in the concept of time and in tolerating ambiguity that can create conflict. For instance, college faculty has far more discretionary time and flexible schedules that do not require them to be at work daily nor to observe set hours. On the other hand, classroom teachers have a much more fixed schedule and a reasonably full teaching day.

Collaboration between university staff and the public or “outreach, as it is usually classified, is not new to Virginia Tech. The university has a long history of providing innovative distance learning techniques, such as satellite videoconferencing, multimedia, interactive video, interactive computer conferencing, and web-based courses, to meet the needs of working adults and nontraditional students. Also, as part of its outreach mission, Virginia Tech is involved in a multitude of economic and community development projects and efforts that focus on education and the dissemination of knowledge.

Nevertheless, despite its outreach efforts, Virginia Tech is essentially a research campus. In a recent update of the Virginia Tech Strategic Plan (2001), as part of its “sense of self” philosophy in its *Mission, Values and Goals* statement, Virginia Tech is described as “a land-grant research university.” The new plan highlighted the overall university goal in the following way: *Virginia Tech Will Be Ranked Among The Top 30 Universities By 2010*. To achieve this, the plan proposed to ensure that promotion and tenure or post-tenure reviews emphasize the research and scholarship goals of the university; to review and analyze program areas to assess quality and research productivity; to increase research expenditures by 10%-12% per year; to increase sponsored research funding from the National Institutes of Health (NIH) and other sources by 20% per year for research programs in the biomedical, biotechnology, and life sciences areas; to provide continued support for research and scholarship, in addition to the special initiatives, for individual faculty and departments; and to support and expand collaborative research efforts with other universities.

In his message to the campus, the President further outlined this research emphasis in the following terms:

...To be successful in raising its national and international reputation, Virginia Tech must have a cluster of programs that are considered to be among the best in the world...The Top 30 research universities in the nation that already possess this critical mass of resources have research programs growing at an increasing rate. The gap is widening between the top 30 and the top 100 universities. Universities that have large-scale research programs are able to quickly take advantage of emerging opportunities. They also have the ability to assume greater risk and the potential for greater return on investment...Virginia Tech is aggressively repositioning its research programs to align them with major sources of funding. In addition, we are modifying our management and organizational structure to be more responsive to opportunities and better interface with both the public and private sectors (<http://www.unirel.vt.edu/stratplan/#message.html>).

Priorities on the campus and within departments therefore reflect and support this research agenda.

Virginia Tech is not alone in this research emphasis. There has been an increasing trend in most American universities toward research. Historically, the mission of American universities and the basis for their early growth was the education of undergraduates. However, their emphasis on the research function and the production of new scientists associated with it has created imbalances between graduate and undergraduate education and between professors as researchers and as teachers (Morin 1993: 101). One problem is that research competes with teaching and other university missions for time and efforts. Moreover, one of the characteristics of the high value placed on “pure” research in the universities is that scientific prestige is associated mainly with research. Therefore, outreach, however rewarding, is commonly regarded by academic scientists and students as a diversion from their research. As Terrence so aptly explained in a 2002 pre-workshop interview:

...When you start writing a proposal you get your science down and you know you budget that out and then you look at what’s feasible and what kind of money do you think you can get and if, if you think you can get more money, then you start talking about pieces such as outreach...let’s say you propose a budget and it has an outreach component and then they cut your budget. And they say well you’ve got x amount of dollars, the reality is I mean that’s a lot of times the outreach component is what’s targeted and you know, I don’t know if that’s the pc thing to say but that’s what happens cause you know we’re scientists and so we want to do what we, what we’ve been trained to do and what we’re skilled to do and therefore, that’s often the first category...

A second problem is that tenure and promotion are essentially based on a record of research and publication. “Both knowledge and its management in the research university are mainly organized in terms of academic departments, which are virtually autonomous in their control of hiring, tenure, curriculum and award of advanced degrees. Each of these departments embodies and transmits to its apprentices the accepted content and methods of a particular scientific discipline” (Morin 1993: 102). This departmental

control of employment and prestige acts as a drag on the ability and willingness of academic scientists to participate in outreach efforts. Scientists must carefully balance and justify the amount of time they give to endeavors not related to the research function. This is exemplified in the following comment made by Melissa, a faculty scientist from the Fisher Group seeking tenure in her Department:

Now, it's sort of a catch twenty-two because at a research university like Virginia Tech, outreach is not an important part of getting tenure. It is one component of it but it is lower on the list than other things that the university considers to be more important, at least for this, for my department...

In terms of network building, outreach endeavors are specific types of enrolment strategies used to gain supporters and expand scientific networks. In the Geosciences Department, this strategy appeared to be an important priority. For instance, browsing through the Department's official website, I came across a listing of various programs referred to as "Outreach Programs": the Geosciences Museum, the Seismological Observatory, the Geothermal Data WWW Page, the Paleontology Online and the Earth Science Resource Page (<http://www.geol.vt.edu/outreach/outreach.html>). The presence of these programs indicates that the basis for expanding the nanotechnology network was already in place in the Geosciences Department. Along with the university's overall outreach mission, these Department programs provided the shell for the NCDP's insertion into the nanotechnology network.

A closer look at the list also revealed that these efforts were primarily internet resources and did not involve the level of interactive engagement with any public or non-scientific group as outlined in the Fisher (2000) proposal. Consistent with the research trend at Virginia Tech and with the notion that departments embody and transmit the accepted views of its institution, one can only surmise that on a hierarchy of values in the

Geosciences Department, outreach was somewhere toward the bottom of the list. As James from the Fisher Group stated in a 2002 pre-workshop interview, “outreach is not in [our] normal way of thinking” because the “Geosciences is programmed” to never “really let you stop and think about what you’re going to do afterward.” Thus, the outreach project proposed by the Fisher Group was perhaps the most visible, interactive endeavor seeking to build collaborative teams between scientists and the public.

On one hand, scientists like Melissa recognized the value of the outreach, since she felt that “it’s terrific and I wish...that people had more of an interest in that. I’m happy that the NSF is encouraging people to incorporate outreach in their research and in fact, at this point, you have to have some sort of outreach component in order to get funding. So, they’re really emphasizing it and I think that that’s causing scientists to think a little bit differently about outreach.” On the other hand, she was also aware of the tendency to downplay or treat outreach as a secondary endeavor:

...it’s an important part. You have to demonstrate that you’ve participated in some sort of outreach but you can’t get tenure from doing outreach and if you spend too much time on it, then it’ll take away from the other parts of your package. So, our department is a strong research department. We want to move up in the rankings, the national research council rankings, and outreach is not necessarily gonna get us there...So, as much as I can try to do that, I will but I know that I can’t spend a whole lot of time on outreach because it’s not gonna benefit me in terms of my career, but as a scientist, you know I would like to incorporate that as long as it doesn’t take away too much time from my research.

The scientist is not the sole inventor but exists within a socio-political network in which he or she must weigh priorities. He or she is part of a larger network or social structure that has the power to sanction or reward his or her efforts. On one hand, the National Science Foundation wanted outreach and the success of the NCDP could play a critical role in further funding. On the other hand, the Geosciences Department did not stress outreach. This created conflict as Melissa noted that the NCDP was “not the most

important thing for [her] career. I try to do both but there's sometimes, sometimes is a conflict inside myself about that." This inner conflict could be likened to Merton's (1973) social ambivalence which describes the "painful contrast" between normative expectations and actual behavior; a situation that contradictory demands place on people in general [in this case scientists] when faced with conflicting values, statuses and roles.

The conflict between spending time on outreach, which did not translate into rewards like career advancement, and spending time on a rigorous research agenda was even more intense for Stacy whose primary research interests in the Department was outreach:

I have really been alone much of the department where it was my job to do it but you can't do it alone, you need the scientists there, you need the grad students there, and if it's not seen as necessary or is peripheral then you know they don't want to do it generally, it's not important...It'll be great to the department because you know I'm hoping that the department will get some credibility with teachers. That's another thing I want to do. Our department is very research oriented and to have teachers see them as successful, I'm hoping to build those. If the department should benefit from that, I'm hoping that the scientists will benefit.

In part, because her collaborative efforts with public schools were not recognized in the university's promotion, merit and tenure structure, in May 2004, she left the university.

This contradiction between outreach and research agendas created conflict especially for scientists as it related to the amount of time spent on research versus outreach. Rachel complained, "...we're supposed to be doing our research and this has taken three weeks out of that already." This time factor is even more important for graduate students when we consider that Traweek (1988) has shown that graduate students are often afraid of losing their chance at success by losing time. Scientists also felt that "there need not be a big meeting to discuss every little thing" as this conflicted their own research time.

Dissemination and Publicity

Actor-network theorists pose that “the predictable character of technoscience is entirely dependent on its ability to spread networks further” (Latour 1987: 249-250). Using the concept of translation, they show that some actors will try to enrol others in positions that suit their interests because the larger the network, the more advantage an actor has in aligning others to his or her cause. Dissemination and publicity are important mobilizing strategies to the growth of a scientific network as enrolment and mobilization of new actors give it strength, power and credibility.

In and of itself, the NCDP can be seen as an enrolment strategy used to expand the nanotechnology network because it was a small part of a larger initiative by the NSF to disseminate nanotechnology to the public, specifically in K-12 education. According to Mihail “Steve” Roco – head of NSF’s nanotechnology initiative, in a speech delivered to some Virginia science teachers at a conference (Fall 2002) which Stacy helped to organize, “the future of nanotechnology depends on nurturing youngsters and exposing them to its advanced multidisciplinary nature.”

In his hour long talk, Roco provided teachers with the following rationale for nanotechnology curriculum: unless, businesses, educators and researchers equip the next generation of workers: America’s schoolchildren, the economic power of small tech would go unrealized.” Comparing nanotechnology to the information technology industry in Germany, he explained that because German schools were not producing skilled computer technicians, the information technology industry never took off. To avoid a similar crisis in the U.S. with nanotechnology, it is essential that companies

“work closer with universities and schools to help build a critical mass of potential small tech workers.”

Roco also estimated that within the next 10 to 15 years, about two million nanotech-trained workers would be needed to support growing and startup industries. “The business implications are that we need to find ways to motivate students about the sciences, and create a pipeline for the future work force.” To this end, he noted that universities like Virginia Tech receiving NSF funds should partner with elementary, middle and high school teachers to write grants for developing instructional materials and to establish nanotechnology curricula in public schools, which teach about 50 million children from kindergarten through grade 12. Recalling the enthusiasm he encountered during a speech to about five thousand (5,000) high school students who for four (4) hours after his speech bombarded him with questions about nanotechnology, he said, “That’s the type of enthusiasm [that] needs to be infectious in U.S. secondary schools.” He saw the goals of the NCDP as very important to the NSF’s mission (Kranz 2002).

Simply put, in his speech Roco expressed a basic actor network premise: to build and expand a network, we need more actors. Their enrolment can be achieved through dissemination and publicity. To date, there are many actors contributing to the expansion of the nanotechnology network through science education projects involving online curriculum and hands-on experience. For example, one program at the University of North Carolina Chapel Hill allows middle and high school students to explore the nanoscale properties of viruses “hands-on” using a set of devices known as the nanomanipulator. Using computers, students are able to visualize and manipulate output from the Atomic Force Microscopy (AFM) in a virtual reality setting.

At Rice University, the Center for Biological and Environmental Nanotechnology (CBEN) has several educational outreach efforts, including a middle school program where students build designer “kids” with atoms, a high school program that focuses on teacher training, an undergraduate program and a program for interested people from the community. The Columbia University Nanocenter has an educational outreach program that includes research experience, seminars, and internships for undergraduates, visits to selected high school classrooms, small group visits to the nanocenter, visiting scholars program, annual retreats, and a career day in nanotechnology. At Cornell University, the NanoBioTechnology Center’s K-12 Education Program includes a traveling museum display “It’s a Nano World,” a summer institute for middle and elementary school teachers, middle school science program for girls, high school “science trunks,” development of a children’s book about nanotechnology, high school student internships, Montessori curriculum development program with kits that contain different modules for grades K-4 and specific lesson plans for K-12 curriculum.

The University of Wisconsin-Madison has an extensive program entitled “Exploring the Nanoworld” where they developed resources for K-12 and college programs including kits, modules for high school teachers, a video lab manual and movies. They also have programs such as Internships for Public Science Education and research experiences for teachers and undergraduates. Another interesting project involves learning about nanotechnology with LEGO bricks. Here at Virginia Tech, NanoSonic Incorporated started by a professor, developed high school kits that demonstrate how to build nanoscale electronic devices. Already these inexpensive ten

dollar (\$10) kits have been distributed to about twenty (20) different schools, including some in Europe.

At the time of this case study, the NCDP was the only workshop incorporating specific Earth Sciences applications into high school curriculum. Thus, going into the second workshop, there was some pressure for the team to produce something that would make a significant contribution to the NSF agenda. Already, the project had been featured in the Spring 2003 issue of the Geosciences Department's Newsletter in a one page article entitled "*Departmental Research Informs Nanoscience Education.*" The article presented an overview of the 2002 workshop participants, objectives and activities and photographs of scientists and teachers working together (2003: 12). Elsewhere, I have indicated the importance of enrolling nonhuman actors like inscription devices to scientific network construction and expansion. They help convince others to join the network by stabilizing scientific claims.

At the end of the first workshop, participants agreed to construct and employ a variety of inscription devices to help spread the word to potential supporters: production of a book or a curriculum resource guide and a nanotechnology poster, attendance at professional meetings such as the Virginia Association for Science Teachers (VAST) and the Geological Sciences Association (GSA), purchase of an inexpensive microscope, creation of a project website and lesson plans specific for high school classrooms. However, before the start of the second workshop in June 2003, only three of these tasks were completed. Stacy and James developed a website, including a discussion board for workshop participants, which became available by March 2003. The website highlighted the project's rationale and overview, the participants, workshop events, contact

information and web links to journals, articles, government, academic and non-profit organizations sites and other curriculum development and outreach programs. A nanotechnology poster was created featuring the participants, instruments and activities of the 2002 workshop.

To encourage other actors to join the nanotechnology “bandwagon,” thereby expanding the network, workshop participants recognized that they had to publicize to high school science and mathematics teachers not directly involved in the NCDP: “it would have to be sold to teachers.” In the Fall of 2002, teachers, scientists and project directors collaborated to present papers and posters¹ at professional meetings. Teachers like Megan and Kate saw their involvement in professional meetings as a way to mobilize new supporters for nanotechnology and for curriculum development in particular:

...You know, I think a big way that, something that we will need to do if we are gonna sell it is to go to some science teachers conferences and present or go into the class because that's what really sell people is seeing how much you're, how excited you are about it and they'll go: WOW, I can do that too!

...the teachers have to be convinced that this is gonna be, this is gonna be something important...Nanotechnology? What's this word, what does this mean? I mean how do I teach this because I don't know anything about it. And so, that's when the teachers go to the internet and start digging up things...through VAST, like if we could set up a booth or something, nanotechnology, how nano, how to use nanotechnology in the classroom, that's all we need is a big banner, and...they might just walk by and go nanotechnology? What is that? Why and they might feel a little bit like I did, like scared, like I don't know what that is, I don't know if I should go ask and I feel stupid cause I don't know and somebody keep walking and then, they get down, you know they get to some other booths and they think, I'm gonna go back and see what that is. Cause they you know, teachers of course have to be curious. So, they come back...then they pick up literature, so like, like if the, our committee or our project could actually put out some literature, like brochures or something and we would have that at VAST and teachers will walk by cause they're always picking up, you know, literature. And, I, it could be as much as just this is what Tech's doing, this is our project, this is what we're trying to do, we're trying to develop labs that teachers can use...you see what's gonna happen is, you're gonna hit the science teachers.

By attending these meetings, workshop participants also realized that getting other high school teachers excited about a science in which many have little knowledge

would not only require some training but it would also involve scientists' ability to effectively utilize rhetorical devices devoid of technical jargon. Scientists would have to break down nanotechnology concepts to a level that was relevant for teachers. Their ability to make meaningful connections was very important to expanding the network as Anthony described his experience at VAST when a scientist presented his work to some high school teachers:

I could see the look of confusion on the peoples' face, much like the way we were the first year that we got involved in the project...but that's just on certain parts. Like on the part that MY group presented on, they could understand because it was more on a high school level...but like the other part was just that kind of tell them about nanoscience and how it was used and [the scientist] did his little force curves and stuff like that and they were like, they were looking dumbfounded.

Testing lesson plans in the high schools before implementation was another important aspect of mobilizing other actors. As Jenna commented:

"I don't want to spend a lot of time working on something [that] isn't gonna be useful and isn't gonna be correct. Teachers are the audience. They don't want anybody wasting their time. Nobody does. When you're in an educational institution, you have people wasting your time all the time at meetings and conferences and things like that. And you don't want someone to hand you a lab and say well try this, this is really good and then, find out that it doesn't really work. And you've got the wrong information.

By the Fall of 2003, a few teachers began testing the lessons in their classrooms. Jenna kept a small group (about ten Chemistry students) after school to help collect data and determine whether or not lesson plans worked under practical classroom conditions.

With the group, she talked a "little bit about nanotechnology." Although, students thought the lesson was "fun" and they were "receptive to pretty much anything that [she] had them do," she claimed:

what I think interested them more than nanotechnology was that they were helping me collect data on a lab that I was writing and working on at Virginia Tech. You know, when they realized that it was a lab that nobody else, no students had done yet, that was, that was more exciting for them I think. You

know but I needed their help, you know I can't do this without you, I need your help, you know. We're writing this but we're not really sure what's gonna happen, and, you know that interested them...it wowed them that they were helping me to write something new that hadn't been written before.

This revealed that actors may be motivated to join the network for reasons unrelated to other actors' interests or even related to the science endeavor at hand.

Standards of Learning (SOL)

In the NCDP, the "Standards of Learning" (SOL) was a major nodal point of conflict that affected actors' enrolment in the network. In general, the term "standards" have multiple meanings. According to Bowker and Star (1999), standards are a way of classifying the world; they embody goals of practice and production that are never perfectly realized; they have significant inertia; and they can be very difficult and expensive to change. Ezrahi (1990) further points out that standards perform a latent function: they are bases of authoritative and accountable structures. A working definition of the term "standard" can be adopted from Eisner (1994) which refers to a level of performance required to receive some sort of certification. In a sense, standards define the knowledge and skills needed to confer success.

Standards in education are thought to perform this function. Moreover, Eisner (1994: 8) points out that "a fundamental tenet of the current educational reform effort is the belief that American schools desperately need standards." The national thrust to ensure high standards in both instruction and student achievement is frequently traced to the publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983). This report portrayed the performance of American students as mediocre and called for reform of the entire U.S. education system.

Ravitch (1995) identified several reasons for this increased preoccupation with setting precise educational standards for students; some of which include the following: measured declines in student achievement in the late 1970s; public discontent over poor performance by American students on international assessments in the 1980s; increased public opinion in the 1980s that schools should be judged not only by their “inputs” but also by their “outputs” or levels of performance; persistent gaps in the educational achievement of students from different ethnic and racial groups; a perception that the American workplace needed more skilled workers; concern that poorly educated youth might impair the nation’s competitive place in the world economy and lack of agreement among educators, parents, and the business community about what students should learn.

Spurred by the ideas in *A Nation at Risk*, the effort to implement more specific standards for what students learn gained national prominence in 1989 when the National Governors Association endorsed national education goals. President George Bush then followed with his support for the formation of the National Education Goals Panel (1990). This panel of governors, business and community leaders, parents and educators resolved that American education needed to change. It needed to increase expectations for student performance and show results (Jennings 1998).

This interest in creating and supporting high standards in education continued with the Clinton administration. In 1994, Congress enacted Goals 2000: Educate America Act. The act contained four elements designed to transform American public education (Arons, 1997). First, state governments were required to adopt content standards for public school curricula. Second, students were expected to demonstrate competency over the determined content material as a prerequisite for promotion and

graduation. Third, supporters of Goals 2000 sought to create systemic changes in all aspects of schooling including textbook development, teacher certification, curriculum content and student assessment. In essence, the legislation called for “development of national standards in education, for tests to measure the achievement of those standards by students, and for aid to states and local school districts to raise their standards” (Jennings 1998: 111).

Though the Goals 2000 standards were not mandatory, in order to access federal funds that supported the legislation, states had to comply. Each state had to develop its own content standards; to develop and submit an annual “state improvement plan” to the U.S. Department of Education; and to develop a process for ensuring that its program for teacher and administrator licensure was aligned with its content and performance standards. As a result many state departments of education and school districts began to push for rigorous curricula and higher standards in student achievement. They began to develop frameworks of content standards and student performance standards that clarify what and how well all students should learn (Harris and Carr 1996).

The commonwealth of Virginia is just one of the many states to implement such a program to require all students to attain a certain level of proficiency on state-mandated standards. In the summer of 1995, the Virginia Board of Education adopted new rigorous academic standards set forth in the Standards of Learning (SOL) for grades K-12 in four core subject areas: Mathematics, Science, English, and History and Social Studies (<http://www.pen.k12.va.us>). According to the former Governor George Allen, these “standards represent a response to the demands of parents throughout Virginia for higher standards and focus on academic courses in public schools, so that our schoolchildren

will be challenged to reach higher and prepared to compete successfully increasingly competitive 21st century” (Allen 1995: ii).

The SOL provided “a blueprint” outlining “the basic knowledge and skills that Virginia schoolchildren should be taught” (Board of Education 1995). They set clear, rigorous and measurable academic expectations for student learning and achievement. They set targets and expectations for what teachers need to teach and students need to learn. The requirement was designed to provide greater accountability on the part of public schools and give local school boards the autonomy and flexibility to offer programs that met the students’ educational needs.

In all four core areas, curriculum framework or SOL documents were provided that detailed the specific knowledge and skills students must possess to meet the standards for these subjects (Appendix D). These documents suggested a greater emphasis on enabling students to reason and think critically, solve authentic problems and make more productive use of instructional time to enrich their educational experiences (Lavigne and Lajoie 1996). In order to achieve these changes, teachers should move away from traditional teacher-centered classroom practices, such as lectures, to a more student-centered context that allows student to work collaboratively and cooperatively to develop learning skills (Kilpatrick and Davis 1993).

Early in the Nanotechnology Curriculum Development Project (NCDP), I overheard teachers’ making cynical remarks about the SOL. Some openly voiced concerns about their ability to develop curriculum that could incorporate the SOL. From their comments, I began to sense that the SOL could affect participants’ ability to effectively expand the nanotechnology network to high school students and other science

and mathematics teachers. Initially, scientists did not seem concerned about the SOL. In a pre-workshop interview, when asked by project directors how they saw the outreach project supporting teaching of the SOL in science education, they did not even know what the term meant or how it related to their project:

Well that would be hard for me to comment on because I don't know much about the national standards, but I think again the tying in of a real world project in a real interesting scientific application with the processes will help students, give them a little bit more initiative in seeing what scientists can actually do with physics and chemistry I think will provide impetuous and maybe spark some interest in some students who may not realize that they are interested in science because they get bored by the way that science is taught without understanding the potential applications and the potential good things that can come out, I mean there are the standard applications, but this nano stuff is really interesting and new and its wide open, there are tons of things that can be done.

Scientists' lack of knowledge and teachers' continued concern about the SOL led project directors to ask Kate who had previously worked on a SOL committee to develop criteria for Earth Sciences to explain the Virginia high school system and the SOL. Describing the SOL and her involvement on the SOL committee, Kate stated:

... you say okay well there's ten minerals we need to know and everybody in the state needs to know these ten minerals and there's fifteen rocks and everybody needs to, and that kind of thing so, then we sat down and did the criteria which I think it came out to be something like 25, 28 pages or things, and then, so for example, plate tectonics, there's books on plate tectonics that has 300, 400 pages. Well, these kids only need to know certain things about it, right. So, you'd sit down and say, okay they're gonna learn this, they're gonna learn this, they're gonna learn this, they're gonna learn this and it was, it's very specific... It's just the standards of learning and they should say every kid that comes out of Earth Science should know this... Every kid comes out of Biology should know this.

The SOL, therefore, provided precise criteria for what students should or should not learn in the classrooms, and mandated exactly what teachers should be teaching.

According to Marsh and Roundtree (1997), assessment is the heart of any standard-based system, providing specific information about how well students are doing. Following the adoption of the SOL, the Virginia Department of Education developed

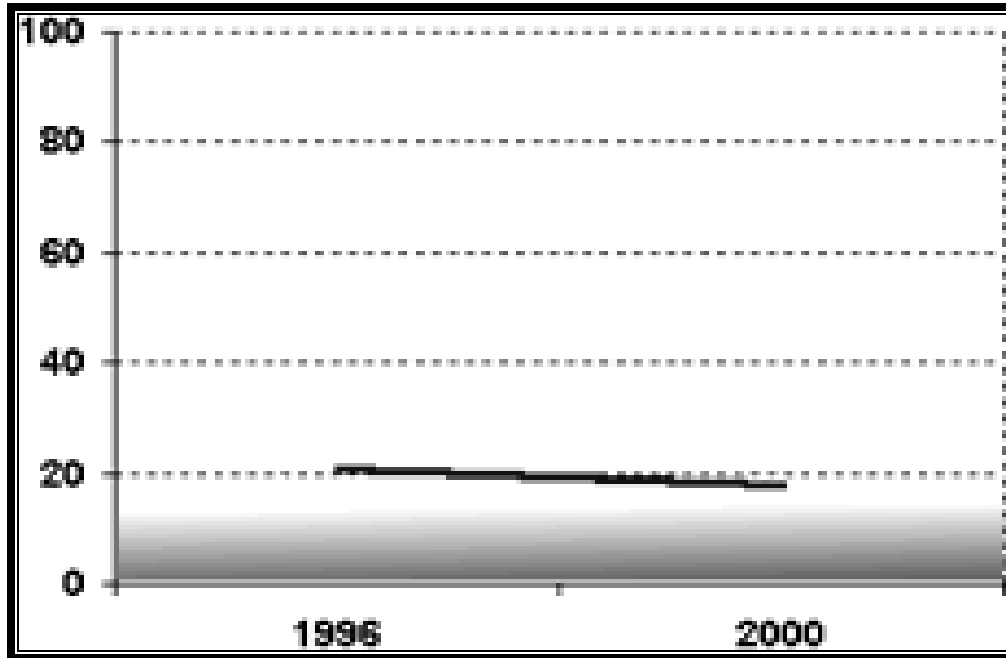
assessment programs designed to assess the extent to which students learned the contents and skills specified in the SOL. In Virginia, this testing began in the spring of 1998 for all students in grades three (3), five (5) and eight (8), and in high school with their results made public in January 1999. Beginning the 2004-2005 school year, the SOL tests became connected to graduation requirements for students. To attain verified credits required for graduation, students had to pass a prescribed number of SOL tests in each subject. Failure to do so would mean “they won’t get the diploma. [Instead], they get a diploma of attendance” for having completed high school credits.

SOL tests are also linked to the accreditation status for schools. Beginning in 1999, Virginia began accrediting schools based on students’ tests scores. In each school seventy percent (70%) of the students had to pass and by 2007, schools will lose accreditation if it falls below the 70% rate. Hence school quality is evaluated on student scores and by implication, teachers are judged based on their students’ test performance. According to McMillan (1998), some consequences include teachers losing contracts and teachers and administrators being transferred or losing their job. To Gary, the curriculum project director in the NCDP, the SOL was merely “a political move so the Governor [could] say yes, our schools are doing something.”

When the workshops began (June 2002), teachers faced an added complication to the heavy emphasis on the SOL in high schools: a government policy drive to support President Bush’s education agenda. In January 2002, the President signed into law the *No Child Left Behind (NCLB) Act of 2001*— a law that contained “the most sweeping changes to the Elementary and Secondary Education Act (ESEA) since it was enacted in 1965” (<http://www.ed.gov/nclb/landing.jhtml>). Asserting that despite a nearly two hundred

(\$200) billion dollar increase for education, “America’s schools [were] not producing the science excellence required for global economic leadership and homeland security in the 21st century” [Figure 6.1], the President introduced the NCLB act to “close the achievement gap among all students and ensure high academic standards.”

Figure 6.1: Proficiency in Science by Percentage of Twelfth Graders (1996-2000)



Source: <http://www.ed.gov/nclb/overview/importance/edlite-index.html>

Key areas to be addressed in the President’s plan included: “measurement of student progress, accountability for every school and the school division, highly qualified instructional staff in all classrooms, English proficiency for limited English speaking students, increased parental involvement, and learning environments that are safe, drug free and conducive to learning” (<http://www.ed.gov/nclb/overview/intro/execsumm.html>).

Starting in the 2002-2003 school year, individual schools and the school division as a whole were to be held accountable for reaching state-established target goals. The new law required that annually at least 95% of all eligible students take the SOL tests, and that tests be developed for students in grades four (4), six (6), and seven (7) where

previously there had been none. NCLB guidelines also outlined rewards for schools making progress and sanctions for schools and divisions needing improvement. By asking schools to describe their success in terms of what each student accomplished, the President changed the role of the federal government in K-12 education.

The NCLB Act did not replace the SOL. Instead, it placed added pressure on teachers who were expected to maintain standards for learning and achievement already required under Virginia's SOL program. The SOL tests were to be used to satisfy the NCLB act's yearly progress requirement. Teachers involved in the workshops explained that there were several reasons for the SOL and the President's plan. In her presentation during the first workshop, Kate categorized these reasons as "the good, the bad and the ugly of SOL":

The Good – Greater accountability would lead to the enhancement of the school system since the SOL could be a good tool to ensure that teachers who are not doing their job as well – "the real targets of SOL" – could improve. Another teacher noted that the SOL could be used to develop some equity through comparisons of SOL testing scores from different schools. For new teachers, for teachers who prefer structure or for those who find it difficult to organize and keep on track with their own curriculum, the SOL criteria provide "a blue print...all you have to do is figure out a lesson plan and how you do it differently allowing some flexibility."

The Bad – For a teacher like Kate whose Earth Sciences SOL document contained roughly fourteen (14) standards with each consisting of several sections in which students must be able to identify rocks and minerals or be able to use computer skills in a variety of ways, teachers must prepare students to be tested in all areas. This task is made more

difficult by the fact that the teachers do not actually write the SOL test. Rather “the professional publishing companies write the test.” This, explained one teacher, creates a fear of teaching among teachers because they have to “stick to the list.” It “takes away a lot of creativity.”

The Ugly – Passing the SOL tests is one criterion for a student’s promotion. This can have a detrimental effect on the students’ psyche as Kate revealed that on the night before the SOL examination, her fourth grader niece threw up and could not sleep. Furthermore, to ensure that teachers are doing their jobs, their salary levels and raises are directly connected to student performance on the SOL tests.

Following Kate’s discussion, scientists began to recognize that the SOL could hamper their ability to develop nanotechnology curriculum that would be disseminated into high schools. For one thing, as another teacher pointed out, the freedom to introduce new, creative nanotechnology lessons into such a structured framework was virtually non-existent. Second, teaching along the SOL guidelines consumed much of the teachers’ time during the school year. Any extra activities would have to be included “after the SOL,” which meant that teachers may never actually get to it, as epitomized in by Kate’s comment below:

...we’re still pushed to cover what’s in the SOL and nanotechnology is not in the SOL right now...they’re gonna have to change it, to add that. And I think when they change it, then we’re gonna be ready with starting the groundwork right now, so that when SOL and nanotechnology pops up in the SOL, oh, what’s out there? Well, Virginia Tech just did all this teamwork you know and they can go and actually use, use this project as a resource. Again, right now, it’s still at the point that we’re trying to get through the material and we take our SOL test in the second week of May which still leaves us about three weeks and so that’s when I’m planning to bring some more stuff in and use some nanotechnology and that type of thing and get the kids more fired up about it and interested in it and that type of thing, once we’ve got that SOL stuff behind us. Cause when we can relax a little bit, we can experiment, we can play around, we can look up, you know, look up information on it and that type of thing. Cause right now we’re pushed for time especially with the snow days, we’ve missed two weeks, we’ve got to

get everything in, which you know, it's a shame that you have to save it to the end... So, it's, it's something like right now, they can't, we, it's really such a push, shove to get the topics covered...

The message was clear: if workshop participants created lesson plans that ignored the SOL, teachers would not be able to use it. According to Anthony:

...From what I saw, the presentations that the graduate students over here did, I can see how it can affect the world because you're able to do a lot of stuff with it but as far as like in the classroom, maybe, it would introduce kids to it and maybe they will have something, have familiarity with it when they go on to college but you can only, pretty much touch the surface in a high school class I believe...Because you have so many other things you need to do, you know with SOL requirements which you can weave this in with SOL a lot but you are just, in a way, you discussing the same things you always discuss but now you have another example to illustrate your point.

The SOL as a nodal point of conflict for the expanding the nanotechnology network was frustrating to scientists as Charles openly stated that if they were not going to use any of these things they taught the teachers, then what was the purpose for them being there:

“There is no point to doing outreach, if it is going to end up in the SOL.”

Teachers were very concerned about whether or not they could develop whole lessons plans that focused entirely on nanotechnology. Some suggested abandoning the idea of a whole lesson plan for each subject and simply doing “five minute blurbs” in high school classrooms. As Jenna stated:

I foresee it being a problem because we as teachers probably spent the last several years streamlining...we do so we can cover all of the SOLs and this, giving the, offering one more thing to the teachers, this is not gonna help them streamline what they've been doing. So, you know, that to me is a problem with any curriculum development right now that anybody is doing, not just this project.

Realizing that the biggest external issue affecting scientists' ability to enrol teachers was the SOL, one of the scientists (Melissa) suggested that they should not develop anything new. Teachers proposed that lesson plans be “specific...we have to relate it specifically to the SOL.” They had “to find something to replace content already taught. They can't

teach anything new...it needs to not be in addition to what [we] do, it needs to replace something that [we]’re already doing. So, it needs to be another way to teach what [we]’re already teaching.”

During the second workshop, project directors, scientists and teachers realized that to be successful in enrolling high school students and other science teachers, they had to work within the confines of the SOL. As Sam, a graduate student scientist, admitted:

...What I got from this interaction is that they have SOL for Physics, Chemistry, Math, Biology, okay and the nanoscience thing that we are trying to push in, actually has components of all. So, if I say it’s only, we know Winogradsky Column, I can’t say that this is Biology. It’s Biology, little bit of Physics, little bit of Chemistry, everything. If I talk about the AFM structure, it’s Physics, it’s Math. So, it’s very something, new that’s not already in those specific SOL that we have to put in, we can push them in. It won’t be much. It would be a very little addition and if that gives them a better understanding of what we are trying to talk about in the nanoscience curriculum, it will work. But, if it’s like just introduced as a nanoscience SOL, I don’t think people would be interested.

When teachers, scientists and project directors met to develop actual lesson plans during the second workshop, they shifted focus to using sample national and Virginia SOL guides to help them align nanotechnology curriculum to support the SOL. Rather than produce a completely new and specific nanotechnology curriculum for high schools, they developed ways to integrate nanotechnology into the existing high school curriculum. Having approached curriculum development in this way, most felt that it was a “good start.” By the end of the second workshop, they completed rough drafts of approximately six (6) lesson plans (See Appendix E for sample of lesson plan draft).

This approach limited the scope of lessons and lab activities as Anthony noted:

...with the way education is set up, with testing and all that, that’s all it could be...It’s an engagement... not bigger than, I mean like we did, we developed those two labs that we had, I think maybe it’s, it might be four labs but I’m not sure...But and those labs all illustrate specific points but again they just took the curriculum that they had and weaved nanoscience within it. You know, so therefore, it still is used as an example, as an example.

Despite its limitations, teachers were pleased that scientists and project directors took their advice to weave nanotechnology concepts into their existing curriculum instead of developing an entirely new nanotechnology curriculum. At first, many could not see, as Anthony expressed, “how [they] could, weave it into the curriculum... probably because [they] didn’t really understand the nanoscience part.” Though “surprised in the direction” they went, Daniel noted that “like four days ago, I would not have predicted lessons anything like what have today,” but it turned out “better than we predicted.”

Scientists were also content with their progress as noted by Sam’s comment below:

This is one of the ideal examples of educating the, I won’t call it, nonscientific mass but people you are not directly involved in the scientific process about the new things that are coming out. And, it’s very nice. I mean the way we made the AFM tool and Rachel’s things and the column, they were beautiful. So, in my opinion...things are okay. Things are very nice but, and it’s on schedule too.

Project directors felt that they accomplished a lot given the timeframe and the complications of the SOL. For example, in 2003 post workshop interviews, Gary noted that he thought they were “pretty successful in getting drafts down...the SOL [was] embedded in the lessons very easily,” and Stacy felt that the problem of the SOL was “dealt with” and that they could forge ahead with the new challenge of testing it in the classrooms – “see[ing] who incorporate[d] it and how they [did] it.”

As we can see the SOL as a nodal point of conflict presented a significant external constraint on scientists’ ability to effectively enrol teachers in curriculum development. This was also complicated by other issues related to the SOL and the Virginia education system. For example, some teachers encountered problems as it pertained to testing lesson plans since nanotechnology was “new science which [was] not covered by [SOL] tests.” When Kate was contacted by Stacy during the Spring of 2004 to determine if she

would test lesson plans in her classroom, although, she agreed to do so, she indicated that it would have to wait until “after the SOL”:

...the thing of it is you've got to cover this [SOL] and then, you can have your creativity...I used to have them do solar systems and you'd go half way around the room, we'd tape them up, and then, we did the geologic timescale and it'd go half way around the room. I had them on strips of paper and the kids would draw on them and put the dates and times and get a little bit, you know, for creativity, especially for the right brain people, since they're more artistic. Give them a chance to shine and feel good about themselves, but those things take 3 days and 3 days here and 3 days there, and you got 10 snow days...that's what I'm saying when, before the SOL it was very creative and the kids, you know it's like, oh we're gonna have fun today, we're gonna do this and now, with SOL, it's kinda like alright we got to cover this material, you're gonna have this on the SOL test, we're gonna get you ready for it. And yeah, their graduation depends on it.

Another issue was participants' ability to develop curriculum that could easily fit into each subject area – Physics, Chemistry, Biology, Earth Sciences and Math. Initially, 2002 pre-workshop interview with scientists revealed that they did not foresee that this would be a potential setback to their goals and considered nanotechnology's interdisciplinary nature as an advantage to the NCDP:

I think that it's one benefit this project has in that regard is that it covers just about every discipline you can think of. You know everything from chemistry to biochemistry to microbiology. Of course geochemistry, physics in the design of the instrument that we are using and so this wide range of disciplines definitely brings that to science education.

However, teachers, being aware of the reality of the education system recognized that nanotechnology's interdisciplinary scope was a problem. As Megan stated, “it seems like there is so much stuff we could do, and that's the problem.” To resolve this, at the start of the 2003 workshop, Stacy suggested that they develop an “interdisciplinary curriculum” – one that could be effectively transferred into any of the subjects. But, as Anna noted the structure of the education system “with Math being done here, Chemistry there” restricted this ability. Furthermore, she confided that because “the schools [were] set up like that and even the tests [were] set up like that,” “...the SOL [made] it look as if

interdisciplinary teaching just [was] not the way to go because they [were] not written that way.”

Another issue was the disparity within the high school education system between laboratory work and high school assessment. For instance, while teachers should spend at least fifty percent (50%) of their time doing laboratory work with their students, the entire SOL test was multiple-choice: there was a disconnect with what the state said and what was actually tested. Another issue related to the SOL was that it “[said] stay up on current events” such as nanotechnology. However, “they don’t test on that.” If participants developed curriculum that focused heavily on lab work and nanotechnology content, it would not be used because students were not being tested on either.

In Virginia, the amount of funding for high schools is tied to property taxes. This raised important issues about equity and access for poorer areas as compared to more affluent regions like Northern Virginia where many schools have more resources, facilities and computers. For this reason, teachers in the NCDP felt that they were more likely to use lesson plans in their Honors classes, thereby limiting the expansion of the network to a certain type and number of high school students. Lack of access to the “equipment and real activities that involved things going on at the nano scale” also constrained the expansion of the network as it limited students’ actual interaction with nanotechnology and therefore, full enrolment in the network.

To resolve these problems, scientists and teachers improvised using simple, cheap materials and tools already available in most schools or from any local craft store as substitutes for the sophisticated instruments that scientists typically used in their experiments. For instance, in developing the microbe-mineral interaction experiment,

fluorescent beads were used to represent bacteria, a plastic soda bottle to produce a column, and regular paper and scotch tape to make a workable funnel. Despite the improvisation, some teachers like Kate, Jenna and Megan continued to worry that without the “untouchable” AFM and SEM, the lessons would not be “meaningful.” Kate felt that a push to include nanotechnology in the SOL could resolve this problem:

...the way that education, how they provide for education is that you have to have teachers excited about it first, then the teachers have to come up with useable labs and materials and then, that they can use, and then the teachers ask for it...with the SOL when they start a revision of the SOL one thing they will probably do is say: okay, they'll probably contact me and say we're gonna revise the SOL. Do you want to be on the committee? And I'll say, yes and one of the things I will say well I think we should put in something in there about nanotechnology...So, then, it's in the SOL, BOOM! It starts of an explosion. So, now it's in the SOL. We have to teach something about nanotechnology. Now, we need the equipment...it's kind of like a filtering process, and if, if it doesn't start going down through the pipe, it doesn't go out into the community.

Thus we can conclude that if the SOL or the school structure through its SOL framework provided a space for nanotechnology, then it could effectively insert itself into the high schools, thereby expanding the network.

Summary and Conclusions

I began this Chapter by pointing out the interdependence of nodes in the network: each node affects and has the potential to affect (positively and/or negatively) the other. For scientific networks, this can cause the size of the network to expand or decrease. This case study showed that external factors adversely affected the actors' enrolment in the network, thereby limiting the growth of the network: university research agenda, dissemination and publicity, and standards of learning (SOL).

In the Geosciences Department, although the basis for expanding the nanotechnology network was already existent in the shell of outreach programs and Virginia Tech's outreach mission, the university research agenda created conflict for

participants. The NSF's outreach objective of school-university collaboration clashed with the university's research function; one which was strongly tied to scientists' tenure and promotion in the Department, as well as graduate students' pressure to complete their dissertations in a timely fashion. This affected the time scientists invested in collaborating with teachers (both workshops lasted four days) and in disseminating nanotechnology to other science and math high school teachers through professional meetings, thereby decreasing their ability to enrol additional supporters and expand the network.

Merton (1973: 270) asserted that "the institutional goal of science is the extension of certified knowledge." This case study revealed that building and expanding scientific networks require the transfer of knowledge to other actors so that supporters can be mobilized to accept one's claims. As more supporters are enrolled to one's claims the network expands and gains credibility. Since nanotechnology is not yet "normal science" but considered "science in the making," dissemination and publicity to actors not involved in the NCDP played important roles in extending knowledge and enrolling supporters to one's claims.

Through inscription and rhetorical devices – newsletters, photos, website, posters, abstracts and presentations at professional meetings – workshop participants attempted to "sell" nanotechnology to other science and math high school teachers, thereby lengthening the size of the network and giving nanotechnology more credibility. However, scientists' inability to use the "right" rhetoric (that is, breaking down the complex jargon) at professional meetings limited teachers' potential interests in enrolment in the network.

Elsewhere (Chapter Two) I explained the importance of government policy through funding and initiatives in legitimizing nanotechnology claims. In this Chapter, we saw that government policy constrained the growth of the nanotechnology network. In this case study, the Virginia SOL had to be considered when expanding the network. The existing school structure in teaching and assessment (i.e. the SOL) and the NCLB criteria impinged on the actors' ability to achieve their goals by limiting the scope and focus of lesson plans. In so doing, it also limited the network's growth since curriculum development was the NCDP's mechanism for mobilizing new actors – high school students and other science and math teachers – into the network. The SOL was a major nodal point of conflict that led workshop participants to engage in constant negotiations and improvisations to reframe the development of lesson plans.

Other factors related to the SOL, that is, lack of interdisciplinary focus in high schools, disparity between lab activities and high school assessment, unavailability of funds, unequal access to resources, facilities, computers and nanotechnology equipment, also impacted curriculum development. As Latour (1987) rightly stressed, it is not just a matter of each of the actors in the chain either resisting or transmitting the information in the same form that they received it, but that their shaping of that information is essential for its continued existence. These external factors led participants to improvise, negotiate and reframe their work within the confines of the SOL and classroom capabilities. This reveals that there is no one way to build a scientific network. It further shows that expanding scientific networks required participants to craft an entry point for nanotechnology by constantly changing strategies to align NCDP's interests to external policy interests. Only when and if the SOL provided a “space” and accepted

nanotechnology into its policy framework could project directors, scientists and teachers in the NCDP hope to enter high schools and reach high school students.

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- ¹ The following is a list of the poster and paper presentations at professional meetings for the year 2002:
- a. “Nanoscience Project with Secondary Science Teachers: Cutting Edge Scientific Research and Curriculum Development” at the Association for Educators of Science Teachers in October 4-5, 2002, Natural Bridge, VA. Authors were the two project directors and the Chemistry teacher.
 - b. “Nanobiogechemistry of microbe/mineral interactions – poster presentation” at GSA National Meeting in October 27-30, 2002, Denver, Colorado. Participants were two scientist and the Earth Sciences teacher.
 - c. “Nanoscale Processes in the Environment: Secondary Teachers and Nanobiogechemistry of Microbe/Mineral Interactions” at GSA in October 27-30, 2002, Denver Colorado presented by the two project directors.
 - d. “Nanoscience and Secondary Science Curriculum Development” at VAST, November 8-9, Richmond, VA. Participants included the two project directors, five teachers and one nano-geoscientist.

Chapter Seven: CONCLUSIONS

This case study focused on understanding what factors go into, and how these factors affect, the construction and expansion of scientific networks. The sociology of scientific knowledge (SSK) literature indicates that actors' ability to legitimize their claims is fundamental to network growth and stability. In the nanotechnology context, the review of literature addressed essential components of legitimizing claims because it is through legitimation processes such as scientific expertise, funding, inscriptions, rhetoric, markets, policy and coalition-building that scientific networks expand and become solidified.

The purpose of this study was to describe and analyze a small part of the network of actors, events, rhetorical strategies, practices and instrumentation – the knowledge production education processes – that went into the construction and growth of a new science called nanotechnology. In order to understand how these processes were being anchored in the network, I addressed the following research questions:

- What actors were enrolled in the nanotechnology network?
- What actors' interests and motivations affected the network?
- What internal factors affected the network?
- What external factors affected the network?

Lessons Learned

A case study does not draw our attention to what could be generalized from the single case. Rather it helps us determine what specifically could be learned from looking at a particular case. Therefore, this conclusion addresses the following question:

- What does this case study help us understand about scientific networks like nanotechnology – its configuration, construction and growth?

From this case, we see that network building and expansion involves multiple kinds of relationships, interactions and associations which are neither fixed nor unchallenged. Each node operates within situational contexts that can positively or negatively affect the entire network. These contexts provide spaces for or establish barriers to inserting and anchoring scientific practice. For any new science to build or expand its network, there needs to be open spaces, that is, right conditions for actors' enrolment into the network. In this case study, I found that Virginia Tech's outreach mission, the Geosciences Department's outreach programs and the Fisher Group's research history all provided appropriate spaces for the Nanotechnology Curriculum Development Project (NCDP) to join the network of actors attempting to enrol more supporters.

Consistent with actor network theory (ANT), this case study also showed that human and nonhuman actors are essential to network construction and expansion. It is usually much easier to understand the role of human actors in this task: without people involved in scientific research and publication, there can be no network. However, we are admonished by SSK theorists that the role of nonhumans are equally significant. Without the machines and instruments, scientists could not do nanotechnology; they could not produce papers and write articles that could be seen by other potential supporters. They could not make discoveries that lead to recognition, credit and funding. In essence, they would not have the "tools" to convince others of the capabilities of this new science and thereby expand its network.

In this case study, I found that the instruments played an even greater role since scientists were initially unable to effectively transfer knowledge to high school teachers through lectures and presentations. Teachers needed to “see” nanotechnology at work to remain interested. In this case, I observed that it was during their lab experiences that teachers were most excited and receptive to scientists’ claims. This indicates that in constructing and expanding scientific networks, nonhuman actors have just as much force and power to strengthen scientific claims and persuade potential supporters to join the network.

This case also showed that scientific networks are built and expand from no single, pure set of interests and motivations. Rather a host of personal and professional interests provided the basis for actors’ involvement in the network, that is, whether or not actors choose to join or exit the network. They also helped shape the knowledge-education production processes as actors sought to promote their own interests over others in some cases. Because these interests were many, actors had to find ways to mobilize everyone in the network or as Latour (1987) explains, to transform others’ interests and make their participation in the workshops a necessity to them. For example, when curriculum development did not serve the Department of Education or the teachers’ interests due to the limitations of the Standards of Learning (SOL) participants worked together to reframe (transform) curriculum content, focus and scope so that nanotechnology could find a space to enter the high schools, thereby enrolling high school students into the network.

Network building and expansion is a complex, dynamic social process that occurs over time. In other words, actors do not immediately join a network. Through the use of

enrolment strategies like rhetorical and inscription devices, actors are persuaded to accept nanotechnology claims and join the network. However, joining the network does not necessarily mean that actors will stay in the network. To keep them anchored to the network, key representatives or as Latour (1987) classified them “spokespersons,” that is individuals who act as mouthpieces for others, must constantly negotiate and reshape their interests to other actors’ interests.

In this case study, I found that through rhetorical strategies, project directors and scientists attempted to problematize issues in ways that teachers would accept their definitions by calling to their defense statistics, equations, formulas, graphs and sketches as well as by employing rhetorical themes like the “social utility,” “endless frontier” and “inevitability of progress” principles to project the nanotechnology’s impact on teachers’ and student’s lives. This supports the problemization stage in Latour’s translation concept and reveals the importance of negotiation and rhetoric to building and expanding scientific networks.

The presence of negotiation in this case study also indicates that there is no single path to build and expand scientific networks. Rather, in keeping with the SSK literature, constructing scientific networks is a social enterprise – a craft encompassing many social mechanisms like dissemination, publicity, curriculum development and outreach that are essential to network construction and expansion. Through these mechanisms, actors spread the word about nanotechnology to potential supporters and others are pulled into the web of actors working to legitimize nanotechnology claims. Actors’ effectiveness in communicating and transferring knowledge to others helps determine the latter’s enrolment in the network.

Latour (1987) focuses heavily on key actors that go into network construction – texts, machines, labs. However, he pays little attention to identifying and explaining the social processes that constitute scientific networks and influence its growth. For instance, although Callon and Latour acknowledge that “differences in agency and size between actors are the result or outcome of some process of negotiation involving power relations” (Doolin and Lowe 2002: 72), they do little to identify and describe what these relations are and how they are exercised in scientific networks. This case study attempted to address this limitation by examining the notion that there can be internal struggles and external issues [that is, in the context of the relation of one node to another] that place strain on actors’ interactions and links to the network.

In this case study, I identified seven factors within the workshop node – decision making and control, personal interests and agendas, enrolment strategies (lectures and presentations, lab experience), labor distribution, communication and feedback, gender and race and financial compensation – and three external factors – university research agenda, dissemination and publicity and standards of learning – which affected network construction and growth. By examining these struggles and issues, I found that certain social processes – conflict, power, authority and hierarchy – are embedded in scientific networks and exert influence over its growth.

Conflict

Actor network theorists stress interdependency – the “seamless web” – of scientific networks. However, in keeping with Weber, this case study showed that such networks are not simply systems of interdependent structures. I found that scientific networks are also systems in which conflict and tension among interest groups emerge

and remerge. For example, differences in school cultures led to time conflicts and also affected the ways in which high school students could be enrolled in the network. Thus consistent with theorists like Marx, Weber and Dahrendorf who emphasized that conflict underlies all social relations, this case study revealed that conflict was common in the interactions among actors within the workshops.

From this case study, we observe that conflict affects the network: it can determine whether or not some actors choose to stay or leave the network. For example, when Charles felt his ideas were being ignored, he left. Conflict can also prevent some actors from ever creating links to the network. For instance, actors' social characteristics – gender and race – can lead to the exclusion of some actors from scientific networks. In addition, internal and external factors serve to constrain the network, which reveals that the notion of the “seamless web” does not necessarily connote that all interactions are symbiotic. Rather, scientific networks exist in conflict and nodes, although they are a part of the network and important to its growth, can be oppositional. On one hand, this revelation might lead one to conclude that conflict will inevitably destabilize the entire network. On the other hand, this case showed that gender conflicts actually contributed to a greater resolve from female actors to continue their enrolment in the workshops and to pass information on to high school students, particularly their female students. Thus, although conflict is embedded in network building and growth, it does not necessarily lead to the destabilization of the network.

Power

Organizational theorists point out that structures are typically settings in which power is exercised. They also indicate that power should be thought of as being “in and

around” organizations (Mintzberg 1983). This is no exception in this case study.

Although in ANT terms, a network does not possess an outside or inside, it is a particular configuration which nonetheless has a definite structure. Latour (1987:180) identifies this structure as “a net that may seem to extend everywhere.” The decision making and control processes in the NCDP show that power is written into that structure and the configuration of scientific networks (Giddens 1984). Therefore, what we do learn about the social processes constitutive to network building is that when actors set out to build or expand a network, the presence of power is embedded in their interactions and associations with each other.

In this case study, I saw power primarily exercised in the workshops’ decision making processes and the pursuit of personal interests and agendas. Project directors and scientists occupied the powerful positions and therefore, had the ability to make major decisions that influenced others and the ability to make their own concerns and interests count. In this case study, I found that power was exercised by project directors and scientists to bring teachers into compliance with their interests. For example, Stacy’s position as project director enabled her to use her power to enrol others in her outreach interests such as disseminating information at professional meetings despite some actors’ reluctance. We can therefore surmise that in building a network, it is not merely the addition of more actors that gives the network its strength as Latour suggests but it is also the ability of actors to use their power to create and maintain social positions that serve their interests.

In this case study, I found that power provided a basis for mobilizing and enrolling others into the network. In this regard, power was exercised in the following ways:

scientists had power to grant or deny teachers' access to information needed for the latter's enrolment in the workshop. Also, because of the limitations of the SOL, teachers had the power to determine whether their high school students would eventually be enrolled. This case study also showed that even "things" like instruments, tools, machines, drawings, sketches, equations had power to convince teachers that nanotechnology was "cutting edge" and thus, secure their involvement and later, their student's enrolment. These nonhuman actors also had power to limit students' access to the real microbe-mineral interactions and thus, limit the lesson plans and ultimately the students' enrolment.

This case study also revealed that in scientific networks, power relations are not evenly distributed. Some nodes have more power than others, which provide the basis of interdependency among actors who must constantly negotiate and reframe their arguments in order to enrol supporters into the network. For instance, because the Department of Education set the guidelines for curriculum development, project directors, scientists and teachers had no power to create curriculum that dealt solely with nanotechnology if they wanted to achieve their goal of enrolling high school students. The political power structure along with the limitations of the SOL framework shaped what tools could be used, how much nanotechnology could be written into lesson plans, how much time teachers engaged in testing nanotechnology and their ability to get the word out to their students.

Authority

Latour (1987) contends that it is the number of people who enter into the network that indicate the amount of power that has been exercised. However, this case study goes

a bit further in showing that it is not merely the number of people who enter the network but also the quality of people. In other words, enrolling actors of established credibility and authority like the National Science Foundation (NSF), Virginia Tech, the Geosciences Department and the Fisher Group were important to expanding the network to high school teachers. Teachers confided that they applied to the project because they knew of Virginia Tech's and the Department's reputation. Thus, scientists' rational-legal authority, that is, the belief in the right of those in higher offices to have power over subordinates, provided a basis for teacher enrolment.

In the NCDP, teachers frequently made distinctions between scientists and themselves, referring to scientists as "real" scientists. This authority enhanced scientists' perceived competence and the legitimacy of scientists' claims. Authority enabled teachers to listen to project directors and scientists. It also meant that scientists could use authority as a tool to defend their claims, to convince others and to make and control decisions that determine and affect others' enrolment. In this case study, scientists' authority, based in their professional expertise, was exercised as a form of "currency" that was converted in rhetorical ways to persuade teachers to accept nanotechnology claims and to pass it on to their students.

Hierarchy

As it stands, the notion of the network as a "seamless web" does little to convey the idea that hierarchies exist in scientific networks. However, consistent with Johnston (1997), I found that in school-university collaborations, "we live in tensions between hierarchy and mutuality... There are forms of hierarchy that lead to domination and control and other hierarchies that allow for shared leadership and work." We have only

to look at the financial compensation structure to see the existence of hierarchy in the NCDP. As gleaned from salary allocations, some actors' interests and positions were held in higher regard than others because of their professional expertise and academic credentials.

Ordinarily hierarchies can create tension and disrupt the network. However, in this case study, I found that although there was some form of hierarchy in place, the actual collaborative endeavor was structured less hierarchically. This enhanced teachers' commitment to the network. Formal distinctions based on rank were less important and through collaborative brainstorming sessions, attempts were made to distribute decision making processes.

This type of hierarchy led to shared work and a sense of appreciation. It helped reduce tension among teachers who felt that those in the authority positions – project directors and scientists – behaved in supportive and sensitive ways toward them, deemphasizing status differences, taking an interest in them as “human beings” (Jenna's words in a post workshop interview), listening to their ideas and suggestions and involving them in some decisions. The participation techniques enhanced participants' sense of personal worth and the importance of all members. They increased their trust and feeling of identification with each other. This had the effect of reducing conflict and divisiveness that are often so typical of hierarchies, and of sustaining the network's growth.

Recommendations

In this case study, actors came from different backgrounds and cultures. For example, Sam was from India and entered the process with a different set of ideas and

approaches to moving nanotechnology out of the laboratory and into the high school classroom. Although Traweek (1988) did an excellent job of showing how cultural differences affect scientific practice, it seems important that we should also explore how actors' cultural backgrounds might affect network building and expansion, particularly when we consider the competitively globalized environment in which nanotechnology work is being conducted.

Nanotechnology is not yet normal science. It is considered science in the making. This brings to mind the question of whether or not differences exist in the social processes, the mechanisms, enrolment strategies, etc. when a science is new versus when it is already established and legitimized like physics or chemistry. To what extent are rhetorical devices, negotiation, power, conflict, hierarchy and authority utilized in established scientific networks versus new areas of scientific research? Comparative studies can be done to understand differences and/or similarities in the role of these social processes for normal science and science in the making. Since nanotechnology is science in the making, I also recommend that longitudinal studies can be done to study its development over time to ascertain what elements and processes become solidified or obsolete as the network expands.

This case study also showed that social characteristics like gender and race are important in influencing actors' enrolment in scientific networks. Actor network theorists have been criticized for ignoring these factors. Therefore, I recommend that more research is needed to explore how these and other factors like actors' age, geographic location or spatial distance and time can affect network construction. Further research is also needed in SSK that point to the prominent role of power, conflict,

hierarchy and authority in shaping the actor network world. Studies should also be conducted that consider how the interactions and associations between and among nodes play interconnected roles in building and expanding scientific networks.

REFERENCES

- Adler, Patricia A. and Peter Adler. 1994. "Observational Techniques." In Norman K. Denzin and Yvonna S. Lincoln (Eds.), *Handbook of Qualitative Research* (377-392). Thousand Oaks, CA: Sage Publications, Inc.
- Akrich, M. 1992. "The Description of Technical Objects." In W. Bijker and J. Law (Eds.), *Shaping Technology or Building Society* (205-224). Cambridge, MA: The MIT Press.
- Allen, George. 1995. "A Message from Governor George Allen." In *Standards of Learning* (i-iii). Richmond, VA: Commonwealth of Virginia.
- Almeida, P. and B. Kogut. 1999. "Localization of knowledge and the mobility of engineers in regional networks." *Management Science*, Vol. 45 (7): 905-917.
- Amato, Ivan. 1991. "A U.S. Lab Opens Doors to the Nanoworld." *Science*, Vol. 254: 1302-1303.
- _____. 1999. "Nanotechnology – Shaping the World Atom By Atom." Washington, D.C.: National Science and Technology Council.
- Amsterdamska, Olga. 1990. "Surely You Are Joking, Monsieur Latour!" *Science, Technology and Human Values*, Vol. 15 (4): 495-504.
- Appenzeller, Tim. 1991. "The Man Who Dared to Think Small." *Science*, Vol. 254 (5036): 1300-1301.
- Arendt, Hannah. 1969. *On Violence*. New York: Harcourt, Brace and World.
- Arons, S. (1997). *Short Route to Chaos*. Amherst, MA: University of Massachusetts Press.
- Baard, Erik. 2003. "Make Robots, Not War." *The Village Voice*, Vol. 48 (37): 39.
- Babchuk, N., K. Bruce and P. George. 1999. "Collaboration in Sociology and Other Scientific Disciplines: A Comparative Trend Analysis of Scholarship in the Social, Physical and Mathematical Sciences." *The American Sociologist*, Vol. 30: 5-21.
- Bailey, C. A. 1996. *A Guide to Field Research*. Thousand Oaks, CA: Pine Forge Press.
- Barnes, Barry. 1974. *Scientific Knowledge and Sociological Theory*. London: Routledge and Kegan Paul Ltd.
- Barry, A. 2001. *Political Machines: Governing a Technological Society*. London:

- Athlone.
- Bastide, F. 1990. "The iconography of scientific texts: Principles of analysis." In Michael Lynch and Steve Woolgar (Eds.), *Representation in Scientific Practice* (187-229). Cambridge, MA: MIT Press.
- Bauer, Henry. 1997. "A Consumer's Guide to Science Punditry." In Ralph Levinson and Jeff Thomas (Eds.), *Science Today: Problem or Crisis?* (22-34). London: Routledge.
- Belsie, Laurent. 2000. "Nanotechnology's Descent into Matter's Minuteness." *Christian Science Monitor*, Vol. 92 (22): 20.
- Berg, Bruce L. 2001. *Qualitative Research Methods for the Social Sciences, 4th Ed.* Needham Heights, MA: Allyn and Bacon.
- Berg, M. and A. Mol (Eds.). 1998. *Differences in Medicine: Unraveling Practices, Techniques, and Bodies.* Durham, NC: Duke University Press.
- Berne, Rosalyn W. 2003. "Ethics, Technology, and the Future: An Intergenerational Experience in Engineering Education." *Bulletin of Science, Technology and Society*, Vol. 23 (2): 88-94.
- Bijker, Wiebe. 1987. "The Social Construction of Bakelite: Toward a theory of invention." In Wiebe Bijker, Thomas Hughes and Trevor Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (159-187). Cambridge, MA: The MIT Press.
- Bijker, Wiebe and Trevor Pinch. 1987. "The Social Construction of Facts and Artifacts." In Wiebe Bijker, Thomas Hughes and Trevor Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (17-50). Cambridge, MA: The MIT Press.
- Bijker, Wiebe, Thomas Hughes and Trevor Pinch (Eds.). 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology.* Cambridge, MA: The MIT Press.
- Bleier, Ruth. 1986. *Feminist Approaches to Science.* New York: Pergamon Press.
- Bloor, David. 1976. *Knowledge and Social Imagery.* Chicago: University of Chicago Press.
- Blume, S. 1992. *Insights and Industry.* Cambridge: MIT Press.
- Board of Education. 1995. "Standards of Learning for Virginia Public Schools." Commonwealth of Virginia.

- Bodgan, R. and S. Taylor. 1975. *Introduction to Qualitative Research Methods*. New York: Wiley.
- Bourdieu, Pierre. 1975. "The Specificity of the Scientific Field and the Social Conditions of the Progress of Reason." In Mario Biagioli (Ed.), *The Science Studies Reader* (31-50). New York: Routledge.
- Bowker, Geoffrey C. and Susan Leigh Star. 1999. *Sorting Things Out: Classification and Its Consequences*. Retrieved January 6, 2003, from <http://weber.ucsd.edu/~gbowker/classification/>
- Branscomb, L. M. and R. Florida. 1997. "Challenges to Technology Policy in a Changing World Economy." In L. Branscomb (Ed.), *Investing in Innovation: Creating a Research and Innovation Policy That Works*. Cambridge, MA: MIT Press.
- Branscomb, L. M., Florida, R., Hart, D., Keller, J., and D. Boville. 1997. *Investing in Innovation - Toward a Consensus Strategy for Federal Technology Policy*. Cambridge, MA: The Competitiveness Policy Council.
- Bryne, E. M. 1993. *Women and Science: The Snark Syndrome*. Washington, D.C.: The Falmer Press.
- Burgess, Jacquelin, Judy Clark and Carolyn M. Harrison. 2000. "Knowledges in Action: an Actor Network Analysis of a Wetland Agri-environment Scheme." *Ecological Economics*, Vol. 35: 119–132.
- Bush, Vannevar. 1998. *Science – The Endless Frontier*, Reprint Ed. North Stratford, NH: Ayer Company Publishers, Inc.
- Byrd, V. 1993. "America's Schools are Not Alone." *New York Times Educational Supplement*, section 4A: 6.
- Callon, Michel. 1986. "The sociology of an actor network: the case of the electric vehicle." In Michel Callon, John Law, Arie Rip (Eds.), *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World* (19-34). London: MacMillan.
- _____. 1986. "Some Elements of a Sociology of Translation. Domestication of the Scallops and the Fishermen of St. Brioux Bay." In J. Law (Ed.), *Power, Action and Belief: A New Sociology of Knowledge* (196-229). London: Routledge and Paul Kegan.
- _____. 1987. "Society in the Making: The Study of Technology as a Tool for Sociological Analysis." In Wiebe. E. Bijker, Thomas P. Hughes, and Trevor J. Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (83-103). Cambridge, MA: The MIT Press.

- _____. 1991. "Techno-Economic Networks and Irreversibility." In John Law (Ed.), *A Sociology of Monsters: Essays on Power, Technology and Domination* (132-161). London: Routledge.
- _____. 1998. *The Laws of the Markets*. London: Blackwell.
- Callon, M. and B. Latour. 1981. "Unscrewing the Big Leviathan: How Actors Macro-Structure Reality and How Sociologists Help Them to Do So." In A.V. Cicourel and K. Knorr-Cetina (Eds.), *Advances in Social Theory and Methodology: Towards an Integration of Micro- and Macro-Sociologies* (277-303). London: Routledge & Kegan Paul.
- _____. 1992. "Don't throw the baby out with the bath school: A reply to Collins and Yearley." In Andrew Pickering (Ed.), *Science as Practice and Culture* (343-368). Chicago: The University of Chicago Press.
- Callon, M. and J. Law. 1995. "Agency and the Hybrid Collectif." *South Atlantic Quarterly*, Vol. 94: 481-507.
- Callon, M., J. Law and A. Rip. 1986. "Putting Texts in Their Place." In M. Callon, J. Law, and J.A. Rip (Eds.), *Mapping the Dynamics of Science and Technology. Sociology of Science in the Real World* (222-228). London: Macmillan.
- Cambrioso, A. and P. Keating. 1988. "Going Monoclonal: Art, Science and Magic in the Day-to-Day Use of Hybridoma Technology." *Social Problems*, Vol. 35: 244-260.
- Carnegie Forum on Education and the Economy. 1986. *A Nation Prepared: Teachers for the 21st Century*. New York.
- Chambers, D. and D. Turnbull. 1989. "Science Worlds: an Integrated Approach to Social Studies of Science Teaching." *Social Studies of Science*, Vol. 19: 155-179.
- Chang, J. P. 2002. "Challenges in Engineering Education of Nanotechnology." *International Journal of Engineering Education*, Vol. 18 (5): 486-487.
- Chia, R., (Ed.). 1998. *Organised Worlds: Explorations in Technology, Organisation and Modernity*. London: Routledge.
- Clark, J. and P. Lowe. 1992. "Cleaning up Agriculture: Environment, Technology and Social Science." *Sociology of Rural*, Vol. 32: 11-29.
- Clark, J. and J. Murdoch. 1997. "Local Knowledge and the Precarious Extension of Scientific Networks: a Reflection on Three Case Studies." *Sociology of Rural*, Vol. 37: 38-60.
- Clarke, A. E. 1990. "A Social Worlds Research Adventure: the Case of Reproductive

- Science.” In S. Cozzens and T. Gieryn (Eds.), *Theories of Science in Society* (15-42). Bloomington: Indiana University Press.
- Clarke, A. and J. Fujimura (Eds.). 1992. *The Right Tools for the Job: At Work in Twentieth-Century Life Sciences*. Princeton, N.J.: Princeton University Press.
- Clarke, A. E. and T. Montini. 1993. “The Many Faces of RU486: Tales of Situated Knowledges and Technological Contestations. *Science, Technology and Human Values*, Vol. 18: 42-78.
- Clarke, Lee. 1992. “The Wreck of the Exxon Valdez.” In Dorothy Nelkin (Ed.), *Controversy: Politics of Technical Decisions*, 3rd Ed. Newbury Park, CA: Sage Publications.
- Claxton, Guy. 1997. “Science of the Times: A 2020 Vision of Education.” In Ralph Levinson and Jeff Thomas (Eds.). *Science Today: Problem or Crisis?* (71-86). London: Routledge.
- Clegg, S. 1989. *Frameworks of Power*. London: Sage.
- Clegg, S. R. 1995. “Book Review of We Have Never Been Modern by B. Latour.” *Theory, Culture and Society*, Vol. 12 (4): 69–78.
- Clegg, Stewart and David Dunkerly. 1980. *Organizations, Class and Control*. London: Routledge and Kegan Paul.
- Clinton., Bill. January 2000. “National Nanotechnology Initiative.” Pasadena, California: <http://www.mrs.org/>.
- CNN.com. “Suddenly, Things are Turning up Nanotech.” Retrieved July 24, 2003, from <http://www.cnn.com/2003/TECH/ptech/07/24/nanotech.products.reut/index.html>
- Collins, Harry. 1981. “Understanding Science.” *Fundamental Science*, Vol. 2: 367-380.
- _____. 1983. “An Empirical Relativist Programme in the Sociology of Scientific Knowledge.” In K. D. Knorr Cetina and M. Mulkay M, (Eds). *Science observed: perspectives on the social study of science*. London: Sage; 1983.
- _____. 1985. “The Possibilities of Science Policy.” *Social Studies of Science*, Vol. 15: 554-558.
- Collins, H. M. and R. Harrison. 1975. “Building a TEA laser: the Caprices of Communication.” *Social Studies of Science*, Vol. 5: 441-450.
- Collins, H. M. and T. Pinch. 1982. *Frames of Meaning: the Social Construction of Extraordinary Science*. London: Routledge.

- _____. 1993. *The Golem: What Everyone Should Know About Science*. Cambridge: Cambridge University Press.
- Colvin, Vicki. "Nanotechnology Research and Development Act of 2003." The House Committee on Science Hearings. Retrieved April 9, 2003 from <http://www.house.gov/science/hearings/full03/apr09/colvin.htm>
- Couldry, N. 2000. *The Place of Media Power: Pilgrims and Witnesses of the Media Age*. London: Routledge.
- Crandall, B.C. 1996. *Nanotechnology: Molecular Speculations on Global Abundance*. Cambridge, MA: The MIT Press.
- Crane, Diane. 1972. *Invisible Colleges: Diffusion of Knowledge in Scientific Communities*. Chicago: University of Chicago Press.
- Crawford, Robert. 1991. "Japan Starts a Big Push Toward the Small Scale." *Science*, Vol. 254 (5036): 1304-1305.
- Crenson, Matt. 1994. "Novel Program III: Undergraduate Nanotechnology." *Science*, Vol. 266 (5186): 864-865.
- Creswell, John W. 1998. *Qualitative Inquiry and Research Design Choosing Among Five Traditions*. Thousand Oaks, CA: Sage Publications, Inc.
- Critchon, Michael. 2002. *Prey*. New York: Harper Collins Publishers.
- Dagani, Ron. February 2000. "NASA Goes Nano." *CENEAR* Vol. 78 (9): 36-38.
- Darling-Hammond, L. and M. W. McLaughlin. 1995. "Policies That Support Professional Development in an Era of Reform." *Phi Delta Kappan*, Vol. 76: 597-604.
- Dea, Data and Ian Scoones. 2003. "Networks of Knowledge: How Farmers and Scientists Understand Soils and Their Fertility. A Case Study from Ethiopia." *Oxford Development Studies*, Vol. 31 (4): 461-478.
- Dear, P. 1995. *Discipline and Experience: The Mathematical Way in the Scientific Revolution*. Chicago: University of Chicago Press.
- Deely, J. 1990. *Basics of Semiotics*. Indiana University Press, Bloomington.
- Denzin, Norman K. and Yvonna S. Lincoln, eds. 1994. *Handbook of Qualitative Research*. Thousand Oaks, CA: Sage Publications, Inc.
- Department of Geological Sciences. Spring 2003. "Departmental Research Informs Nanoscience Education." *Department of Geological Sciences Newsletter*.

- Virginia: Virginia Polytechnic Institute and State University.
- Dickson, David. 1974. *The Politics of Alternative Technology*. New York: Universe Books.
- _____. 1984. *The New Politics of Science*. Chicago Press: University of Chicago Press.
- Domhoff, William. 2002. *Who Rules America?: Power and Politics*. Boston: McGraw Hill.
- Doolin, Bill and Alan Lowe. 2002. "To Reveal is to Critique: Actor-network Theory and Critical Information Systems Research". *Journal of Information Technology*, Vol. 17: 69-78.
- Drexler, Eric. 1981. "Molecular Engineering: an Approach to the Development of General Capabilities of Molecular Manipulation."
- _____. 1986. *Engines of Creation*. New York: Anchor.
- _____. 2002. *Unbounding the Future: the Nanotechnology Revolution*. <http://www.foresight.org>: Foresight Institute.
- DuCharme, Wesley M. 1995. *Becoming Immortal: Nanotechnology, You, and the Demise of Death*. Evergreen, Colorado: Blue Creek Ventures.
- Duhem, P. 1962. *The Aim and Structure Physical Theory*. New York: Atheneum.
- Ebisch, Robert. 2003. "Is Death a Disease"? *Sky: A Traveling Magazine*, December, 89-92.
- Egan, Greg. 1994. *Quarantine*. New York: Harper Collins Publishers.
- Eisner, E. W. 1994. Do America's schools need standards? *The School Administrator*, 8-15.
- Eisenhart, M. A. and E. Finkel, (Eds.). 1998. *Women's Science: Learning and Succeeding From the Margins*. Chicago: University of Chicago Press.
- Ellis, Patricia. 2003. "Women in Science-Based Employment: What Makes the Difference"? *Bulletin of Science, Technology and Society*, Vol. 23 (1): 10-16.
- Epstein, Steven. 1993. "Impure Science: AIDS, activism and the politics of knowledge." Ph.D. Dissertation. Berkley: University of California.
- _____. 1995. "The Construction of Lay Expertise: AIDS Activism and the Forging

- of Credibility in the Reform of Clinical Trials.” *Science, Technology and Human Values*, Vol. 20 (4): 408-437.
- Esterberg, Kristin G. 2002. *Qualitative Methods in Social Research*. United States: The McGraw-Hill Companies, Inc.
- Evans, Robert, Simon Guy and Simon Martin. 1999. “Making a Difference: Sociology of Scientific Knowledge and Urban Energy Policies.” *Science, Technology and Human Values*, Vol. 24 (1): 105-131.
- Ezrahi, Yaron. 1990. *The Descent of Icarus: Science and the Transformation of Contemporary Democracy*. Cambridge, Massachusetts: Harvard University Press.
- Fahley, Jonathan. 2001. “The Science of Small.” *Forbes*: <http://www.forbes.com>.
- Fairley, Peter. 2001. “The Start of Something Big.” *Chemical Week*, Vol. 163 (45): 23-27.
- Feder, Barnaby J. February 2003. “Technology: From Nanotechnology’s Sidelines, One More Warning.” *The New York Times*.
- Feyerabend, P. K. 1975. *Against Method: Outlines of an Anarchistic Theory of Knowledge*. London: New Left Books.
- Feynman, R. P. December 1959. “There’s Plenty of Room at the Bottom: An Invitation to Enter a New Field of Physics.” <http://www.its.caltech.edu/~feynman> or <http://www.zyvex.com/nanotech/feynman.html>
- Fisher, Steve. November 2000. “NSF Proposal - Nanoscale Processes in the Environment: Nanobiochemistry of Microbe/Mineral Interactions.” Department of Geological Sciences, Virginia Polytechnic Institute and State University.
- Franz, Neil and Kara Sissell. 2001. “Technology and Environment.” *Chemical Week*, Vol. 163 (38): 44.
- Freedman, David H. 1991. “Exploiting the Nanotechnology of Life.” *Science*, Vol. 254 (5036): 1308-1310.
- Friedkin, Noah E. 1998. *A Structural Theory of Social Influence*. Cambridge, England: Cambridge University Press.
- Friedman, Michael. 1998. “On the Sociology of Scientific Knowledge and its Philosophical Agenda.” *Studies in History and Philosophy of Science*, Vol. 29 (2): 239-271.
- Fujimura, Joan. 1987. “Constructing ‘do-able’ problems in cancer research: articulating

- alignment.” *Social Studies of Science*, Vol. 17: 257-293.
- _____. 1988. “The molecular biological bandwagon in cancer research: where social worlds meet.” *Social Problems*, Vol. 35: 261-283.
- _____. 1992. “Crafting Science: Standardized packages, boundary objects, and “translation.” In Andrew Pickering (Ed.), *Science as Practice and Culture* (168-211). Chicago: University of Chicago Press.
- _____. 1996. *Crafting Science: A Sociohistory of the Quest for the Genetics of Cancer*. Cambridge, MA: Harvard University Press.
- Fuller, Steve. 1993. “A Strategy for Making Science Studies Policy Relevant.” T. Brante, Fuller and W. Lynch (Eds.). *Controversial Science: From Content to Contention* (107-125). Albany: State University New York Press.
- _____. 2000. “Why Science Studies Has Never Been Critical of Science.” *Philosophy of the Social Sciences*, Vol. 30 (1): 5-33.
- Fountain, Renee-Marie. 1999. “Socio-scientific issues via actor network theory.” *Journal of Curriculum Studies*, Vol. 31 (3): 339-358.
- Giddens, Anthony. 1984. *The Constitution of Society*. Cambridge: Polity Press.
- Gilbert, G. Nigel, and Michael Mulkay. 1984. *Opening Pandora’s Box: A Sociological Analysis of Scientists’ Discourse*. Cambridge: Cambridge University Press.
- Ginther, Donna K. 2003. “Is MIT an Exception? Gender Pay Differences in Academic Science?” *Bulletin of Science, Technology and Society*, Vol. 23 (1): 21-26.
- Gittler J. B. 1940. “Possibilities of a Sociology of Science.” *Social Forces*, Vol. 18: 350-359.
- Golinski, J. V. 1990. “The Theory of Practice and the Practice of Theory: Sociological Approaches in the History of Science.” *Isis*, Vol. 81: 492-505.
- _____. 1994. “Precision Instruments and the Demonstrative Order of Proof in Lavoisier’s Chemistry.” *Osiris*, Vol. 9: 30-47.
- Goodlad, John I. 1990. *Teachers for Our Nation’s Schools*. San Francisco: Jossey-Bass.
- _____. 1991-1992. “Striving for a More Perfect Union.” *National Forum Teacher Education Journal*, Vol.1: 7-11.
- Gottweis, Herbert. 1998. *Governing Molecules: The Discursive Politics of Genetic Engineering in Europe and the United States*. Cambridge, Massachusetts: MIT Press.

- Grint, K. and S. Woolgar. 1997. *The Machine at Work – Technology, Work and Organisation*. Cambridge: Polity Press.
- Gross, Michael. 1999. *Travels to the Nanoworld: Miniature Machinery in Nature and Technology*. New York: Plenum Publishing Corporation.
- Guba, E. G. 1990. “The Alternative Paradigm Dialog.” In E. G. Guba (Ed.), *The Paradigm Dialog* (17-30). Newbury Park, CA: Sage.
- Guba, E. G. and Y. S. Lincoln. 1988. “Do Inquiry Paradigms Imply Inquiry Methodologies?” In D. M. Fetterman (Ed.), *Qualitative Approaches to Evaluation in Education: The Silent Scientific Revolution*. New York: Praeger.
- _____. 1994. “Competing Paradigms in Qualitative Research.” In Norman K. Denzin and Yvonna S. Lincoln (Eds.), *Handbook of Qualitative Research* (105-117). Thousand Oaks, CA: Sage Publications, Inc.
- Gubrium, Jaber F. and James A. Holstein. 1997. *The New Language of Qualitative Method*. New York: Oxford University Press.
- Hacking, Ian. 1992. “The Self Vindication of the Laboratory Sciences.” In Andrew Pickering (Ed.), *Science and Practice as Culture*. Chicago: University of Chicago Press.
- _____. 1999. *The Social Construction of What?* Cambridge: Harvard University Press.
- Halfpenny, Peter. 1979. “The Analysis of Qualitative Data.” *Sociological Review*, Vol. 27: 799-823.
- Halfpenny, P. 1991. “Rationality and the Sociology of Scientific Knowledge.” *Sociological Theory*, Vol. 9: 212-215.
- Hall, Richard. 1998. *Organizations: Structures, Processes and Outcomes*. New Jersey: Prentice Hall.
- Hamel, J., S. Dufour and D. Fortin. 1993. *Case Study Method*. Thousand Oaks, CA: Sage.
- Haraway, Donna. 1991. *Simians, Cyborgs and Women: The Reinvention of Nature*. New York: Routledge.
- _____. 1997. *Feminism and Technoscience*. London: Routledge.
- Harding, Sandra, (Ed.) 1993. *The Racial Economy of Science: Toward a Democratic Future*. Bloomington: Indiana University Press.

- Harris, D. E. and J.F. 1996. *How to Use Standards in the Classroom*. Alexandria, VA: Association for Supervision and Curriculum Development.
- Hart, David M. 1998. *Forged Consensus: Science, Technology, and Economic Policy in the United States, 1921-1953*. Princeton, New Jersey: Princeton University Press.
- Hartill, Lane. 2001. "Prizewinning Inventor Has Big Dreams for Nanotechnology." *Christian Science Monitor*, Vol. 93 (59): 12.
- Heaton, George R., Christopher T. Hill, Patrick Windham, David W. Cheney and Tatsujiro Suzuki. 2001. "Public Policies and the Emergence of High-Technology Sectors." *A Report to JETRO-New York*.
- Heath, James R., Phillip J. Kuekes, Gregory S. Snider and R. Stanley Williams. 1998. "A Defect-Tolerant Computer Architecture: Opportunities for Nanotechnology." *Science*, Vol. 280 (5370): 1716-1721.
- Henderson, K. 1991. "Flexible Sketches and Inflexible Data Bases: Visual Communication, Conscriptio Devices, and Boundary Objects in Design Engineering." *Science, Technology and Human Values*, Vol. 16: 448-173.
- Hess, David. 1997. *Science Studies: An Advanced Introduction*. New York: New York University Press.
- Hiskes, Anne L. and Richard Hiskes. 1986. *Science, Technology and Policy Decisions*. Boulder, CO: Westview.
- Hoepfl, Marie C. 1997. "Choosing Qualitative Research: A Primer for Technology Education Researchers." *Journal of Technology Education*, Vol. 9 (1): 47-63.
- Holmes Group. 1986. *Tomorrow's Teachers: A Report of the Holmes Group*. Michigan: Michigan State University.
- <http://www.ed.gov/nclb/landing.jhtml>. "No Child Left Behind." Retrieved June 5, 2004.
- <http://www.ed.gov/nclb/overview/importance/edlite-index.html>. "Why No Child Left Behind is Important to America." Retrieved June 5, 2004.
- <http://www.ed.gov/nclb/overview/intro/execsumm.html>. "Overview – Executive Summary." Retrieved June 5, 2004.
- <http://www.geol.vt.edu>. "Department of Geosciences at Virginia Tech." Retrieved March 19, 2004.
- <http://www.geol.vt.edu/outreach/outreach.html>. "Outreach Programs." Retrieved March 19, 2004.

- <http://www.nanotech-now.com/government.htm>. "Government Nanotechnology Programs." Retrieved April 11, 2003, from
- <http://www.pen.k12.va.us>. "Virginia Department of Education." Retrieved September 13, 2004.
- <http://www.unirel.vt.edu/stratplan/#message.html>. "Updating the University Strategic Plan 2001." Retrieved June 5, 2004.
- <http://www.vt.edu/aboutvt/universityataglance.html>. "About Virginia Tech - University At A Glance." Retrieved March 19, 2004.
- Hughes, Thomas. 1983. *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore, Maryland: Johns Hopkins University Press.
- _____. 1986. "The Seamless Web: Technology, Science, Etcetera, Etcetera." *Social Studies of Science*, Vol. 16 (2): 281-292.
- _____. "The Evolution of Large Technical Systems." In Wiebe Bijker, Thomas Hughes and Trevor Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (51-82). Cambridge, MA: MIT Press.
- Hutchison, James. 2003. "Nanoscience Turns Green." *New Voices in Chemistry*.
- Jasanoff, Sheila. 1990. *The Fifth Branch: Science Advisers as Policymakers*. Cambridge, MA: Harvard University Press.
- _____. 1992. "Science, politics, and the re-negotiation of expertise in EPA." *Osiris*, Vol. 7: 195-217.
- Jennings, J. 1998. *Why National Standards and Tests? Politics and the Quest for Better Schools*. Thousand Oaks, CA: Sage Publishing.
- Johnston, Marilyn. 1997. *Contradictions in Collaboration: New Thinking on School/University Partnerships*. New York: Teachers College Press.
- Jordan, K. and M. Lynch. 1992. "The Sociology of a Genetic Engineering Technique: Ritual and Rationality in the Performance of the 'plasmid prep'." In A. Clarke and J. Fujimura (Eds.), *The Right Tools for the Job: At Work in Twentieth-Century Life Sciences* (77-114). Princeton, N.J.: Princeton University Press.
- Kabanoff, Boris. 1991. "Equity, Equality, Power and Conflict." *Academy of Management Review*, Vol. 16: 416-441.
- Kalb, Claudia. 1999-2000. "The War on Disease Goes Miniature." *Newsweek*, Vol. 134/135 (26): 89-92.

- Keller, Evelyn Fox. 1985. *Reflections on Gender and Science*. New Haven, CT: Yale University Press.
- Kendall, G. and G. Wickham. 2001. *Understanding Culture: Cultural Studies, Order, Ordering*. London: Sage.
- Kilpatrick, J. and Davis, R. B. 1993. Computers and Curriculum Change in Mathematics. In C. Keitel and K. Ruthven (Eds.), *Learning from computers: Mathematics Education and Technology*. Berlin, Germany: Springer-Verlag.
- Kleinman, Daniel Lee. 1998. "Untangling Context: Understanding a University Laboratory in the Commercial World." *Science, Technology and Human Values*, Vol. 23 (3): 285-314.
- Knorr-Cetina, Karin. 1981. *The Manufacture of Knowledge: An Essay on the Constructivist and Contextual Nature of Science*. Oxford, UK: Pergamon Press.
- _____. 1992. "The Couch, the Cathedral and the Laboratory." In Andrew Pickering (Ed.), *Science as Practice and Culture* (113-138). Chicago, IL: University of Chicago Press.
- Knorr-Cetina, K. and K. Amann. 1990. "Image Dissection in Natural Scientific Inquiry." *Science, Technology and Human Values*, Vol. 15: 259-283.
- Knorr-Cetina, K. and M. Mulkay, (Eds.). 1983. *Science Observed: Perspectives in the Social Studies of Science*. London: Sage Publications.
- Kohler, R. 1994. *Lords of the Fly: Drosophila Genetics and the Experimental Life*. Chicago: University of Chicago Press.
- Kranz, Garry. 2002. "Businesses Need To Plant Nano Seeds In Schools, NNI Chief Says." Retrieved May 5, 2003 from, http://www.smalltimes.com/document_display.cfm?document_id=5133.
- Kroker, A. and M. Kroker. 1996. "The Nanotech Future: A Digital Conversation with B. C. Crandall." http://www.ctheory.net/text_file?pick=36
- Kuhn, Thomas. 1962 [1970]. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.
- Kurzweil, Ray. 2003. "The Societal Implications of Nanotechnology." The House Committee on Science Hearings. Retrieved April 9, 2003, from <http://www.house.gov/science/hearings/full03/apr09/kurzweil.htm>
- LaFollette, Marcel. 1986. "The Regulatory Environment for Science, Science Policy

- Study Background Report No. 10.” Washington, D.C.: The Office of Technology Assessment for the Task Force on Science Policy of the House Committee on Science and Technology.
- Lakatos, I. 1970. “Falsification and the Methodology of Scientific Research Programmes.” In I. Lakatos and A. Musgrave (Eds.), *Criticism and the Growth of Knowledge*. Cambridge: Cambridge University Press.
- Lane, Neal. 2001. “The Grand Challenges of Nanotechnology.” *Journal of Nanoparticle Research*, Vol. 3 (2-3): 95-103.
- Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press.
- _____. 1988. *The Pasteurization of France*. Translated by Alan Sheridan and John Law. Cambridge, MA: Harvard University Press.
- _____. 1991. ‘Technology is society made durable’. In John Law (Ed.), *A Sociology of Monsters: Essays on Power, Technology and Domination* (103-131). Routledge, London.
- _____. 1992. “Where are the Missing Masses? The Sociology of a Few Mundane Artifacts.” In W. Bijker and J. Law (Eds.), *Shaping Technology/Building Society* (265). Cambridge, MA: The MIT Press.
- _____. 1993. *We Have Never Been Modern*. Translated by C. Porter. Cambridge, MA: Harvard University Press.
- _____. 1996 [2002]. *Aramis or the Love of Technology*. Cambridge, MA: Harvard University Press.
- _____. 1997. “On actor-network theory: A few clarifications.” Keele, England: Keele University Centre for Social Theory and Technology. Retrieved June 21, 2004, from <http://www.keele.ac.uk/depts/stt/stt/ant/latour.htm>
- _____. 1999a. “Give Me a Laboratory and I Will Raise the World.” In M. Biagioli (Ed.), *The Science Studies Reader* (258-275). New York: Routledge.
- _____. 1999b. *Pandora’s Hope: Essays on the Reality of Science Studies*. Cambridge, Mass.: Harvard University Press.
- _____. 1999c. “On Recalling ANT.” In: J. Law and J. Hassard (Eds.), *Actor-Network Theory and After* (15-25). Oxford, England: Blackwell Publisher.
- Latour, Bruno and Steve Woolgar. 1979 [1986]. *Laboratory Life: The Construction of Scientific Facts*. Princeton: Princeton University Press.

- Lavigne, N.C., & Lajoie, S.P. 1996. "Communicating Performance Criteria to Students Through Technology." *Mathematics Teacher*, Vol. 89 (1): 66-69.
- Law, John. 1986. "On the Methods of Long-Distance Control: Vessels, Navigation and the Portuguese Route to India." In J. Law (Ed.), *Power, Action and Belief: A New Sociology of Knowledge*. London: Routledge and Kegan Paul.
- _____. 1987. "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion." In Wiebe Bijker, Thomas Hughes and Trevor Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (111-132). Cambridge, MA: The MIT Press.
- _____. 1992. "Notes on the Theory of the Actor-Network: Ordering, Strategy and Heterogeneity." *System Practice*, Vol. 5 (4): 379-393.
- _____. 1999. "After ANT: complexity, naming and topology." In J. Law and J. Hassard, (Eds.) *Actor-Network Theory and After*. Oxford, England: Blackwell Publisher.
- Lawrence, C. 1985. "Incommunicable Knowledge: Science, Technology and the Clinical Art in Britain 1850-1914." *Journal of Contemporary History*, Vol. 20: 503-520.
- Layton, Edwin. 1977. "Mirror-Image Twins: The Communities of Science and Technology in the 19th Century America." *Technology and Culture*, Vol. 12: 562-580.
- Lee, Cynthia. 2001. "Feds hope to invest more in nanoscience." *UCLA Today*. Retrieved May 5, 2003, from <http://www.today.ucla.edu/2001/010925nanoscience.html>.
- Lewis, Laura Henderson. 2001. "The New Future of Magnetism." *World and I*, Vol. 16 (9): 146-154.
- Leydesdorff, Loet. 1991. "In Search of Epistemic Networks." *Social Studies of Science*, Vol. 21 (1): 75-110.
- Lieberman, A. 1995. "Practices that Support Teacher Development: Transforming Conceptions of Professional Learning." *Phi Delta Kappan*, Vol. 76: 591-596.
- Little, J.W. 1993. "Teachers' Professional Development in a Climate of Educational Reform." *Educational Evaluation and Policy Analysis*, Vol. 15:129-151.
- Livingston, E. 1986. *The Ethnomethodological Foundations of Mathematics*. London: Routledge and Kegan Paul.

- Longino, Helen. 1990. *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*. Princeton, New Jersey: Princeton University Press.
- Lorsbach, Anthony W. 2003. "The Learning Cycle as a Tool for Planning Science Instruction." Retrieved May 8, 2003, from <http://www.coe.ilstu.edu/scienceed/lorsbach/257lrcy.htm>
- Lowe, Alan. 2004. "Methodology Choices and the Construction of Facts: Some Implications from the Sociology of Scientific Knowledge." *Critical Perspectives on Accounting*, Vol. 15: 207–231.
- Lynch, Michael. 1984 [1985]. *Art and Artifact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory*. London: Routledge and Kegan Paul.
- Lyotard, Jean-Francois. 1984. *The Postmodern Condition: A Report on Knowledge*. Minneapolis: University of Minnesota Press.
- MacKenzie, Donald. 1987. "Missile Accuracy: A Case Study in the Social Processes of Technological Change". In Wiebe Bijker, Thomas Hughes and Trevor Pinch (Eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (194-214). Cambridge, MA: The MIT Press.
- Mackenzie, D. and J. Wajcman, (Eds.). 1985. *The Social Shaping of Technology: How the Refrigerator Got Its Hum*. Milton Keynes, UK: Open University Press.
- Macnaghten, Phil and John Urry. 1998. *Contested Natures*. Thousand Oaks, CA: Sage Publications.
- Malkinson, Terrence. 2002. "Then National Nanotechnology Initiative." *Today's Engineer*: <http://www.todaysengineer.org>.
- Marcuse, Herbert. 1964. *One-Dimensional Man: Studies in the Ideology of Advanced Industrial Society*. Boston: Beacon Press.
- Marsh, D. and M. Roundtree. 1997. "Improving Student Performance: A Lesson from Abroad." *Educational Leadership*, 16-19.
- Martin, Brian and Pam Scott. 1992. "Automatic Vehicle Identification: A Test of Theories of Technology". *Science, Technology and Human Values*, Vol. 17 (4): 485-505.
- Martin, Emily. 1987. *The Woman in the Body: A Cultural Analysis of Reproduction*. Boston: Beacon Press.
- Marx, Karl and Frederick Engles. 1848. *The Communist Manifesto*. Retrieved June 5,

- 2004, from <http://www.anu.edu.au/polsci/marx/classics/manifesto.html>
- Maynard, Douglas W. and Nora C. Schaeffer. 2000. "Toward a Sociology of Social Scientific Knowledge: Survey Research and Ethnomethodology's Asymmetric Alternates." *Social Studies of Science*, Vol. 30 (3): 323-370.
- McGowan, Thomas, M. "Reflections of an Experienced Collaborator." In Henrietta Schwartz (Ed.), *Collaboration: Building Common Agendas*. Washington D.C.: American Association of Colleges for Teacher Education.
- McGuinness, Kevin. 1997. "Fabrics and Nanotechnology." *Futurist*, Vol. 31 (4): 12-16.
- McKelvey, M. 1997. "Co-evolution in Commercialization of Genetic Engineering." *Industrial and Corporate Change*, Vol. 6 (3): 503-532.
- McMaster, T., R. T. Vidgen and D. G. Wastell. 1997. "Towards an Understanding of Technology in Transition. Two Conflicting Theories." Informational Systems Research in Scandinavia, IRIS20 Conference, University of Oslo, Hanko, Norway.
- McMillan, J. H. 1998. "Why Test Scores Aren't Enough." *Virginia Journal of Education*, Vol. 91: 18-19.
- Mehlman, Bruce. 2001. "Shaping Policy for Nanotechnology Development." Los Angeles: <http://www.ta.doc.gov>
- Mehta, Michael D. 2002. "Nanoscience and Nanotechnology: Assessing the Nature of Innovation in These Fields." *Bulletin of Science, Technology and Society*, Vol. 22 (4): 269-273.
- Merchant, C. 1982. *Radical Ecology: the Search for a Livable World*. New York: Routledge.
- Merriam, S. 1988. *Case Study Research in Education: A Qualitative Approach*. San Francisco: Jossey-Bass.
- Merton, Robert. 1973. *The Sociology of Science*. Chicago: University of Chicago Press.
- Merton, Robert and Harriet Zuckerman. 1973. "Institutionalized Patterns of Evaluation in Science (1971)." In Robert Merton, *The Sociology of Science*. Chicago: University of Chicago Press.
- Michael, M. 1996. *Constructing Identities: The Social, the Nonhuman and Change*. London: Sage.
- Miller, P. 1997. "The Multiplying Machine." *Accounting and Organizations in Society*,

- Vol. 22 (3/4): 355–64.
- Million, S.K. and J. W. Vare. 1997. "The Collaborative School: A Proposal for Authentic Partnership in a Professional Development School." *Phi Delta Kappan*, Vol. 78: 710-713.
- Mills, C. Wright. 1959. *The Sociological Imagination*. New York: Oxford University Press.
- Minerd, Jeff. 2001. "Nanotubes Make Handy Devices." *Futurist*, Vol. 35 (1): 15-17.
- Mintzberg, Henry. 1983. *Power In and Around Organizations*. Englewood Cliffs, NJ: Prentice Hall.
- Mol, A. and J. Law. 1994. "Regions, Networks and Fluids: Anemia and Social Topology." *Social Studies of Science*, Vol. 24: 641-671.
- Monge, P. and E. Eisenberg. 1987. "Emergent Communication Networks." In F. Jablin, L. Putnam, K. Roberts and L. Porter (Eds.), *Handbook of Organizational Communication* (304-342). Newbury Park, C.A.: Sage.
- Moody, James. 2004. "The Structure of a Social Science Collaboration Network: Disciplinary Cohesion from 1963 to 1999." *American Sociological Review*, Vol. 69 (2): 213-238.
- Morin, Alexander J. 1993. *Science Policy and Politics*. New Jersey: Prentice-Hall, Inc.
- Morrow, K. John. 2002. "Nanotechnology: Applications to Biotechnology." *Genomic/Proteomic Technology*, Vol. 2 (6): 26-29.
- Morus, I. 1988. "The Sociology of Sparks: An Episode of the History and Meaning of Electricity." *Social Studies of Science*, Vol. 18: 387-417.
- Mukerji, Chandra. 1989. *A Fragile Power: Scientists and the State*. Princeton, N.J.: Princeton University Press.
- Mulhall, Douglas. 2001. "Preparing For Armageddon: How We Can Survive Mega-Disasters." *Futurist*, Vol. 35 (3): 36-42.
- Mullins, Nicholas C. and Carolyn J. Mullins. 1973. *Theories and Theory Groups in Contemporary American Sociology*. New York: Harper and Row Publishers.
- Murdoch J. 1994. "Weaving the Seamless Web: A Consideration of Network Analysis and its Potential Application to the Study of the Rural Economy." Working Paper 3, Centre for Rural Economy, University of Newcastle upon Tyne, Newcastle upon Tyne.

- Murdoch, Jonathan. 1998. "The Spaces of Actor-Network Theory." *Geoforum*, Vol. 29 (4): 357-374.
- Murray, Fiona. 2002. "Innovation as Co-evolution of Scientific and Technological Networks: Exploring Tissue Engineering." *Research Policy*, Vol. 31: 1389-1403.
- National Academy of Sciences. 2003. "Advisers to the Nation." Retrieved April 11, 2003, from <http://www.nationalacademies.org/about/about.html>
- National Commission on Excellence in Education. 1983. *A Nation at Risk: The Imperative for Education Reform*. Washington, D.C.: U.S. Government Printing Office.
- National Commission for Excellence in Teacher Education. 1985. *A Call for Change in Teacher Education*. Washington, D.C.: American Association of Colleges for Teacher Education.
- National Nanotechnology Initiative. 2001. "National Nanotechnology Investment in the FY 2002 Budget Request by the President." Extras from AAAS Report XXVI (225-233). Washington D.C.
- National Science Foundation. 1994. "The National Science Foundation: A Brief History." Retrieved March 19, 2004, from <http://www.nsf.gov/pubs/stis1994/nsf8816/nsf8816.txt>
- National Science Foundation. 2001. "Societal Implications of Nanoscience and Nanotechnology." In M. C. Roco and W. S. Bainbridge (Eds.). Arlington, VA: Author. Retrieved April 22, 2003, from <http://www.wtec.org/loyola/nano/NSET.Societal.Implications/>
- National Science Foundation. 2002. "Report of the Nanogeoscience Workshop." Berkeley, California. Retrieved May 7, 2003 from http://www.nsf.gov/home/crssprgm/nano/geo_workshop.pdf
- National Science Foundation/U.S. Department of Commerce. 2002. "Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science." In M. C. Roco and W. S. Bainbridge (Eds.). Arlington, VA: Author. Retrieved April 11, 2003 <http://www.wtec.org/ConvergingTechnologies/>
- Neuman, W. Lawrence. 2000. *Social Research Methods: Qualitative and Quantitative Approaches, 4th Ed.* Needham Heights, MA: Allyn and Bacon.
- Nisbet, Robert. 1980. *History of the Idea of Progress*. New York: Basic Books.
- Nordmann, Alfred. 2003. "Nanoscale Research: Application Dominated, Finalized or "Techno"-Science"?". University of South Carolina.

- Offer, John. 1996. "Sociological Theory and the Sociology of Scientific Knowledge: A Reply to Steve Fuller." *Sociology*, Vol. 30 (1): 159-162.
- Owen-Smith, Jason. 2001. "Managing Laboratory Work through Skepticism: Processes of Evaluation and Control." *American Sociological Review*, Vol. 66 (3): 427-452.
- Pattatucci, A. M. (Ed.). 1998. *Women in Science: Meeting Career Challenges*. Thousand Oaks, CA: Sage Publications.
- Patterson, Robert S., Nicholas M. Michelli and Arturo Pacheco. 1999. *Centers of Pedagogy*. San Francisco: Jossey-Bass Publishers.
- Patton, M. Q. 1990. *Qualitative Evaluation and Research Methods*. Newbury Park, CA: Sage.
- Peterson, Christine. 2003. "Molecular Manufacturing: The Societal Implications of Advanced Nanotechnology." The House Committee on Science Hearings. Retrieved April 9, 2003, from <http://www.house.gov/science/hearings/full03/apr09/peterson.htm>
- Pickering, Andrew. 1981. "The Role of Interests in High-energy Physics: the Choice Between Charm and Colour." In K. D. Knorr Cetina, R. Krohn and R. D. Whitley, (Eds.). *The Social Process of Scientific Investigation*. Dordrecht: Reidel.
- _____. 1984. "Against putting the phenomena first: The discovery of the weak neutral current." *Studies in History and Philosophy of Science*, Vol. 15: 85-117.
- _____. 1995. *The Mangle of Practice: Time, Agency, and Science*. Chicago: University of Chicago Press.
- Pinch, Trevor. 1986. *Confronting Nature*. Dordrecht: Reidel.
- Porter, Roy. 1978. "Gentlemen and Geology: The Emergence of a Scientific Career, 1660-1920." *Historical Journal*, Vol. 21: 809-836.
- Porter, Theodore M. 1995. *Trust in Numbers*. Princeton, New Jersey: Princeton University Press.
- Press, Frank. 1981. "Science and Technology in the White House, 1977 to 1980: Part 2." *Science*, Vol. 211 (4479): 249-256.
- Quel, John L. 1989. "NanoCon Proceedings." NANOCON.
- Ranson, Stewart, Bob Hinings and Royster Greenwood. 1980. "The Structuring of Organizational Structures." *Administrative Science Quarterly*, Vol. 25:1-17.
- Ravitch, D. 1995. "A Citizen's Guide to Standards." *American School Board Journal*,

35-39.

- Regis, Ed. 1995. *Nano, the Emerging Science of Nanotechnology: Remaking the World – Molecule by Molecule*. New York: Little, Brown and Company.
- Rehg, William. 2000. “Critical Science Studies as Argumentation Theory: Who’s Afraid of SSK?” *Philosophy of the Social Sciences*, Vol. 30 (1): 33-48.
- Roberts, L. 1991. “A Word and the World: the Significance of Naming the Calorimeter.” *Isis*, Vol. 82: 198-222.
- Roco, M.C., S. Williams and P. Alivisatos. 1999. “Nanotechnology Research Directions: IWGN Workshop Report.” Maryland: WTEC, Loyola College.
- Roco, M.C. 2002a. “Research and Development FY 2002.” National Science and Technology Council’s subcommittee on Nanoscale Science, Engineering and Technology. Retrieved April 11, 2003 from <http://www.nano.gov/2002budget.html>.
- _____. 2002b. “Nanotechnology: A Frontier for Engineering Education.” *International Journal of Engineering Education*, Vol. 18 (5): 488-497.
- Rogers, Adam and David A. Kaplan. 1997/1998. “Get Ready for Nanotechnology.” *Newsweek*, Vol. 130 (22): 52-54.
- Rorty, Richard. 1991. *Objectivity, Relativism and Truth*. Cambridge: Cambridge University Press.
- Rose, Hilary and Steven Rose. 1970. *Science and Society*. Harmondsworth: Penguin.
- Rose, Nicholas. 1991. “Governing by Numbers: Figuring Out Democracy.” *Accounting, Organizations and Society*, Vol. 16 (7): 673-692.
- Rossiter, Margaret W. 1993. “The ~~Matthew~~ Matilda Effect in Science.” *Social Studies of Science*, Vol. 23: 325-41.
- Roth, Wolff-Michael and Michelle K. McGinn. 1998. “Knowing, Researching, and Reporting Science Education: Lessons from Science and Technology Studies.” *Journal of Research in Science Teaching*, Vol. 35 (2): 213-235.
- Roth, Wolff-Michael, Michelle K. McGinn and G. Michael Bowen. 1996. “Applications of Science and Technology Studies: Effecting Change in Science Education.” *Science, Technology and Human Values*, Vol. 21 (4): 454-484.
- Rouse, J. 1987. *Knowledge and Power: Toward a Political Philosophy of Power*. Ithaca, N.Y.: Cornell University Press.

- Rudwick, M. 1985. *The Great Devonian Controversy: The Shaping of Scientific Knowledge among Gentlemanly Specialists*. Chicago: Chicago University Press.
- Russell, Jill Frymier and Richard B. Flynn. 1992. *School-University Collaboration*. Indiana: Phi Delta Kappa Educational Foundation.
- Saetnan, Ann Rudinow. 1997. "Standing One's Ground Requires Finding Some Ground to Stand On". In Berner Boel (Ed.), *Gendered Practices: Feminist Studies of Technology and Society*. Linkoping, Sweden: Department of Technology and Social Change.
- Saldanha, Arun. 2002. "Music Tourism and Factions of Bodies in Goa." *Tourist Studies*, Vol. 2 (1): 43-62.
- _____. 2003. "Actor-Network Theory and Critical Sociology." *Critical Sociology*, Vol. 29 (3): 419-432.
- Salkever, Alex. 1999. "Scientists Now Build Machines One Molecules at a Time." *Christian Science Monitor*, Vol. 91 (200): 2.
- Schama S. 1995. *Landscape and Memory*. London: HarperCollins.
- Schiebinger, Londa. 1987. "The History and Philosophy of Women in Science: A Review Essay." In Sandra Harding and Jean F. O'Barr (Eds.), *Sex and Scientific Inquiry* (7-34). Chicago: The University of Chicago Press.
- Schmitt, Bill. 2001. "Biological Boom Seen." *Chemical Week*, Vol. 163 (34): 34-37.
- Schofer, Evan. 2003. "The Global Institutionalization of Geological Science, 1800-1990." *American Sociological Review*, Vol. 68: 730-759.
- Schulz, William G. March 2003. "Nanotech Business Takes Flight." *CENEAR*, Vol. 81 (13): 21-22.
- _____. 2000. "Crafting A National Nanotechnology Effort." *Chemical and Engineering News*: <http://www.pubs.acs.org/cen/nanotechnology>.
- Schwandt, Thomas A. 1994. "Constructivist, Interpretivist Approaches to Human Inquiry." In Norman K. Denzin and Yvonna S. Lincoln (Eds.), *Handbook of Qualitative Research* (118-137). Thousand Oaks, CA: Sage Publications, Inc.
- Scott, Pam. 1991. "Levers and Counterweights: A Laboratory That Failed to Raise the World." *Social Studies of Science*, Vol. 21 (1): 7-35.
- Shapin, Steven. 1982. "History of science and its sociological reconstructions." *History of Science*, Vol. 20: 157-211.

- _____. 1988. "The House of Experiment in Seventeenth-Century England." In Mario Biagioli (Ed.), *The Science Studies Reader* (479-504). New York: Routledge.
- _____. 1995. "Here and Everywhere: Sociology of Scientific Knowledge." *Annual Review of Sociology*, Vol. 21: 289-321.
- Shapin, S. and S. Schaffer. 1985. *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*. Princeton, N.J.: Princeton University Press.
- Short, R. 1991. *Imagined Country: society, culture and environment*. London: Routledge.
- Singleton, V. and Michael, M. (1993). 'Actor-Networks and Ambivalence: General Practitioners in the UK Cervical Screening Programme'. *Social Studies of Science* Vol. 23: 227- 264.
- Smith, Bruce L. R. 1990. *American Science Policy Since World War II*. Washington, D.C.: Brookings Institution.
- Sonnert, G. and G. Holton. 1995. *Who Succeeds in Science?: The Gender Dimension*. New Brunswick, NJ: Rutgers University Press.
- Sorenson, K. H. and N. Levold. 1992. "Tacit Networks, Heterogeneous Engineers and Embodied Knowledge." *Science, Technology and Human Values*, Vol. 17: 13-35.
- Spotts, Peter N. 1999. "The Brave New World of Biotechnology and Beyond." *Christian Science Monitor*, Vol. 91 (233): 17.
- Stake, Robert E. 1994. "Case Studies." In Norman K. Denzin and Yvonna S. Lincoln (Eds.), *Handbook of Qualitative Research* (236-247). Thousand Oaks, CA: Sage Publications, Inc.
- Star, Susan Leigh. 1989a. *Regions of the Mind: Brain Research and the Quest for Scientific Certainty*. Stanford, CA: Stanford University Press.
- _____. 1989b. "The Structure of Ill-Structured Solutions: Boundary objects and Heterogeneous Distributed Problem-solving." In L. Gasser and M.N. Huhns (Eds.), *Distributed Artificial Intelligence, Vol. 2* (37-54). London: Pitman.
- _____. 1991. "Power, Technologies and the Phenomenology of Convention: On Being Allergic to Onions". In John Law (Ed.), *A Sociology of Monsters* (26-56). London: Routledge.
- Star, Susan Leigh and James R. Griesemer. 1989. "Institutional Ecology, "Translation,"

- and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. In Mario Biagioli (Ed.), *The Science Studies Reader* (505-524). New York: Routledge.
- Stengers, I. 1997. *Power of Invention: Situating Science*. Translated By P. Bains. Minneapolis: University Of Minnesota Press.
- Stengers, I. 2000. *The Invention of Modern Science*. Translated By D.W. Smith. Minneapolis: University Of Minnesota Press.
- Strathern, M. 1991. *Partial Connections*. Savage, MD: Rowman and Little.
- Sweeney, Aldrin E., Sudipta Seal and Pallavoor Vaidyanathan. 2003. "The Promises and Perils of Nanoscience and Nanotechnology: Exploring Emerging Social and Ethical Issues." *Bulletin of Science, Technology & Society*, Vol. 23 (4): 236-245.
- Taylor, S., and R. Bogdan. 1998. *Introduction to Qualitative Research Methods, 3rd Ed.* New York: Wiley.
- Teich, Albert H. and June M. Wiaz. 1986. In Albert H. Teich and Jill H. Pace (Eds.), *Science and Technology in the USA*. United Kingdom: Longman Group UK Limited.
- Teresko, John. 2001. "The Incredible Shrinking Computer." *Industry Week*, Vol. 250 (9): 19-20.
- Teschler, Leland. 2000. "The Future Will be Measured In Nanometers." *Machine Design*, Vol. 72 (18): 102-109.
- Thayer, Ann M. 2002. "Nanotech Meets Market Realities." *CENEAR*. Vol. 80 (29): 17-19.
- The Advanced Semiconductor Magazine. June/July 2003. "Nano Growth." Vol. 16 (5): 5.
- The Advanced Semiconductor Magazine. August 2003. "£90m+ for UK Nanotechnology and Industry." Vol. 16 (6): 5.
- The Computer Bulletin, July 2003. "Futureshock: Nanotechnology." Vol. 45 (6): 32.
- The Futurist. June/July 1998. "Nanotechnology Makes Gains." Vol. 32 (5): 17-19.
- The House Committee on Science Hearings. 2003. "The Societal Implications of Nanotechnology." Retrieved April 9, 2003, from <http://www.house.gov/science/hearings/full03/apr09/charter.htm>

- Thom, M. 2001. *Balancing the Equation: Where are Women and Girls in Science, Engineering and Technology?* New York: National Council for Research on Women.
- Thomas, K. 1984. *Man and the Natural World: Changing Attitudes in England 1500-1800*. Harmondsworth: Penguin.
- Thompson, Nicholas. 2000. "Downsizing." *Washington Monthly*, Vol. 32 (10): 25-30.
- Thrift, N. 1996. *Spatial Formations*. London: Sage.
- Traweek, Sharon. 1988. *Beamtimes and Lifetimes: The World of High Energy Physicists*. Cambridge: Harvard University Press.
- Trubowitz, Sidney and Paul Longo. 1997. *How It Works – Inside a School-College Collaboration*. New York: Teachers College Press.
- Trulove, Susan. 2001. "Research group gets \$1.1-million NSF grant." *Arts and Sciences*, Vol. 14 (1): 7.
- Urry, J. 2000. *Sociology Beyond Societies: Mobilities For The Twenty-First Century*. London: Routledge.
- Van Helden, A. 1994. "Telescopes and Authority from Galileo to Cassini." *Osiris*, Vol. 9: 8-29.
- Vaughan, Diane. 1999. "The Role of the Organization in the Production of Techno-Scientific Knowledge." *Social Studies of Science*, Vol. 29 (6): 913-943.
- Verbeke, Karen A. and Patricia O. Richards. 2001. *School-University Collaborations*. Indiana: Phi Delta Kappa Educational Foundation.
- Wacjman, Judy. 1991. *Feminism Confronts Technology*. University Park: Pennsylvania State University Press.
- Walsham, G. 1997. "Actor-network Theory and IS Research: Current Status and Future Prospects". In A. Lee, J. Liebenau and J. DeGross (Eds.), *Information Systems and Qualitative Research: Proceedings of the IFIPTC8 WG 8.2*. London: Chapman and Hall.
- Wang, Linda. 2001. "Getting Nanowired." *Science News*, Vol. 159 (18): 286-288.
- Weber, Max. 1978. *Economy and Society, Vol. 1*. Berkeley: University of California Press.
- Weiss, P. 2001. "Wiring Teensy Tubes, Strands into Circuits." *Science News*, Vol. 160

- (19): 294-296.
- Werthamer, N. Richard, K. Eric Drexler, Susan G. Hadden and Jorge Chapa. 1992. "Nanotechnology: The Past and the Future." *Science*, Vol. 255 (5042): 268-269.
- White, Michael. 1999. *Sir Isaac Newton: Discovering Laws that Govern the Universe*. California: Gale Group.
- Williams, R. 1972. "Ideas of Nature." In J. Benthall (Ed.), *Ecology: the Shaping Enquiry*. London: Longman.
- Winner, Langdon. 1993. "Upon Opening the Black Box and Finding It Empty: Social Constructivism and the Philosophy of Technology". *Science, Technology and Human Values*, Vol. 18 (3): 362-378.
- _____. 2003. "The Societal Implications of Nanotechnology." The House Committee on Science Hearings. Retrieved April 9, 2003, from <http://www.house.gov/science/hearings/full03/apr09/winner.htm>
- Wood, Andrew and Neil Franz. 2001. "Technology and Environment." *Chemical Week*, Vol. 163 (37): 31.
- Woolgar, Steve. 1990. "Time and Documents in Researcher Interaction: Some Ways of Making Out What is Happening in Experimental Science." In Michael Lynch and Steve Woolgar (Eds.), *Representation in Scientific Practice* (123-152). Cambridge, MA: MIT Press.
- _____. 1991. "The Turn to Technology in Social Studies of Science." *Science, Technology and Human Values*, Vol. 16 (1): 20-50.
- Wynne, Brian. 1992. "Carving out Science (and politics) in the Regulatory Jungle." *Social Studies of Science*, Vol. 22: 745-758.
- Yin, R. K. 1989. *Case Study Research: Design and Method*. Newbury Park, CA: Sage.
- Zuckerman, Harriet. 1988. "The Sociology of Scientific Knowledge." In Neil Smelser (Ed.), *The Handbook of Sociology*. Newbury Park, CA: Sage.
- _____. 1991. "The Careers of Man and Women Scientists: A Review of Current Research." In Harriet Zuckerman, Jonathan R. Cole and John T. Bruer (Eds.), *The Outer Circle: Women in the Scientific Community* (27-56). New York: W. W. Norton and Company.

Appendix A: SEMI-STANDARDIZED INTERVIEW SCHEDULE

For Project Directors

1. Please describe the extent of your knowledge of nanoscience and nanotechnology.
2. I noticed that usually when people talk of nanoscience, they use the terms nanotechnology and nanoscience interchangeably. Based on your knowledge and in your opinion, are these two distinct concepts? If so, what are those distinctions and why do you make such distinctions?
3. In general, what are your views about this new science or technology?
4. How do you see nanotechnology impacting society?
5. Many claims are being made by nanotechnology about its contribution to social change in areas of the environment, medicine, housing and construction, conservation, even physical immortality. Do you believe in such claims and what specific ones do you think will become a reality?
6. What do you see as the necessary ingredients that will lead to the success of nanotechnology? And which of these ingredients you have mentioned do you think will be most significant for the success of nanotechnology?
7. How did you come to be involved in the particular project, and what are some of things that motivated you to be a part of this project?
8. What is your specific role(s) in this project? Will this role change during the course of the program? How essential do you think your role is to the outcome of the project?
9. How do you see your specific role contributing to the production of scientific knowledge about nanotechnology?
10. What are your primary goals in this project? What are your secondary goals?
11. What are your views on science and outreach endeavors such as this project? Do you think outreach is important?
12. In your opinion, what are the expectations of NSF in the outreach program?
13. What sort of benefits to self or to others (teachers, scientists, high school students, other participants) you hope to achieve?
14. The ultimate goal is to develop curriculum. How important is it to this particular science?

15. Please describe the extent of your experience in the Geosciences (years and level).
16. Please describe the extent of your experience in outreach endeavors such as this one (years and level).
17. Do you think that this collaborative work with high school teachers will be any different from your other collaborative experiences? Why or why not?
18. Apart from curriculum development, what other hopes and expectations do you have for the teachers? That is, do you see them benefiting from this program and in what ways?
19. What is your personal philosophy of science, that is, how do you view science and technology, and its role in society? What should science be doing?

For Scientists

1. I noticed that usually when people talk of nanoscience, they use the terms nanotechnology and nanoscience interchangeably. In your opinion, are these two distinct concepts? If so, what are those distinctions and why do you make such distinctions?
2. In general, what are your views about this new science or technology?
3. How do you see nanotechnology impacting society?
4. There are many paths to nanoscience – for example, through biology, chemistry, engineering and computer science. What path do you think will have the most significant impact on the field of nanotechnology, and why?
5. Many claims are being made by nanotechnology about its contribution to social change in areas of the environment, medicine, housing and construction, conservation, etc. Do you believe in such claims and what specific ones do you think will become a reality?
6. How do you see your research contributing to any of the claims made by nanotechnology?
7. What are the ingredients that you think might contribute to the production of scientific knowledge about nanotechnology? Which of these do you think is most critical?
8. A lot of money is being poured into this new science. How does this play out in producing knowledge about nanotechnology?

9. How did you come to be involved in nanotechnology?
10. More specifically, how and why did you come to be involved in the outreach project?
11. What was your specific role in the outreach project, and how do you think it contributed to the field of nanotechnology?
12. In general, what are your views on science and outreach endeavors such as this one?
13. Do you think that the Geosciences department places a lot of value on outreach? If so, why or why not?
14. Why do you think NSF is emphasizing such outreach endeavors in this particular field?
15. Initially, what were some of the things you had hoped to achieve in this program? Benefits to self or to others?
16. What is the level and years of your teaching experience in science and technology?
17. Did you think that teaching high school teachers would have been any different? Why or why not?
18. Tell me a bit about yourself – your academic and scientific background. What led you to become a nanoscientist?
19. What is your personal philosophy of science, that is, how do you view science and technology, and its role in society? What should science be doing?

For High-School Teachers:

1. What motivated you to become involved in this project?
2. Is this your first experience with nanoscience? How much past knowledge about nanotechnology do you have?
3. I noticed that the terms nanoscience and nanotechnology seems to be used interchangeably. Of what you know about nanoscience and nanotechnology, do you think these are distinct concepts? Why and on what criteria do you make these distinctions?
4. In general, what are your views about this science – nanotechnology?

5. In what ways, do you think nanotechnology will impact society?
6. In general, what are your views on science and outreach endeavors such as this one?
7. Do you think that this collaborative work between scientists and high school teachers like yourself is important? If so, why or why not?
8. Specifically, how do you feel about your involvement in this upcoming outreach program?
9. What are some of the things you hope to achieve in this program? Benefits to self or to others?
10. What has been your past teaching experience? How many years and what science subjects have you taught?

Appendix B: APPLICATION FORM

Nanoscale Science Curriculum Project

Application

Name _____
School _____
School Address _____

Home Address _____

Phone: School _____ Home _____
E-mail _____
Grades and Subjects taught: _____

Years Teaching Experience _____
Academic Degrees and Institutions _____

Please answer the following questions (typed, on a separate sheet, not to exceed 1 page for each question).

1. What experiences would you bring to enhance this project?
2. Describe your approach to teaching science.

Send your application by mail or email _____ with a recommendation from your principal to:

2. Describe your approach to teaching science.

Appendix C: CURRICULUM DEVELOPMENT SURVEY

Name _____

Nature of Science and Science Teaching

These questions are designed stimulate discussion and to assess our knowledge and values related to the nature of science, scientific research, and science education. Please complete the form by listing your answers or ideas. If you don't address the topic, you may leave it blank.

1. How do you teach about:

a. Scientific theory

b. Research procedures

c. Data collection and analysis

d. Objectivity

e. Cutting-edge scientific research

2. How do you teach about the relationship between science and technology?

3. How do you teach about the connection between science and public policy?

4. How do you see yourself and your students benefiting from the outreach component of the project?

5. How do you think scientists will benefit from the outreach component?

6. How do you think the teaching of science is similar or different from the practice of science?

7. What important concepts do you think secondary science students need in order to understand nanoscale science?

Appendix D: SAMPLE OF STANDARDS OF LEARNING (SOL) DOCUMENT

Mathematics
Standards of Learning

Trigonometry

The standards below outline the content for a one-semester course in trigonometry. A thorough treatment of trigonometry is provided through the study of trigonometric definitions, applications, graphing, and solving trigonometric equations and inequalities. Emphasis should be placed on using connections between right triangle ratios, trigonometric functions, and circular functions. In addition, applications and modeling should be included throughout the course of study. Emphasis should be placed on oral and written communication concerning the language of mathematics, logic of procedure, and interpretation of results. Students enrolled in trigonometry are assumed to have mastered those concepts outlined in the Algebra II standards.

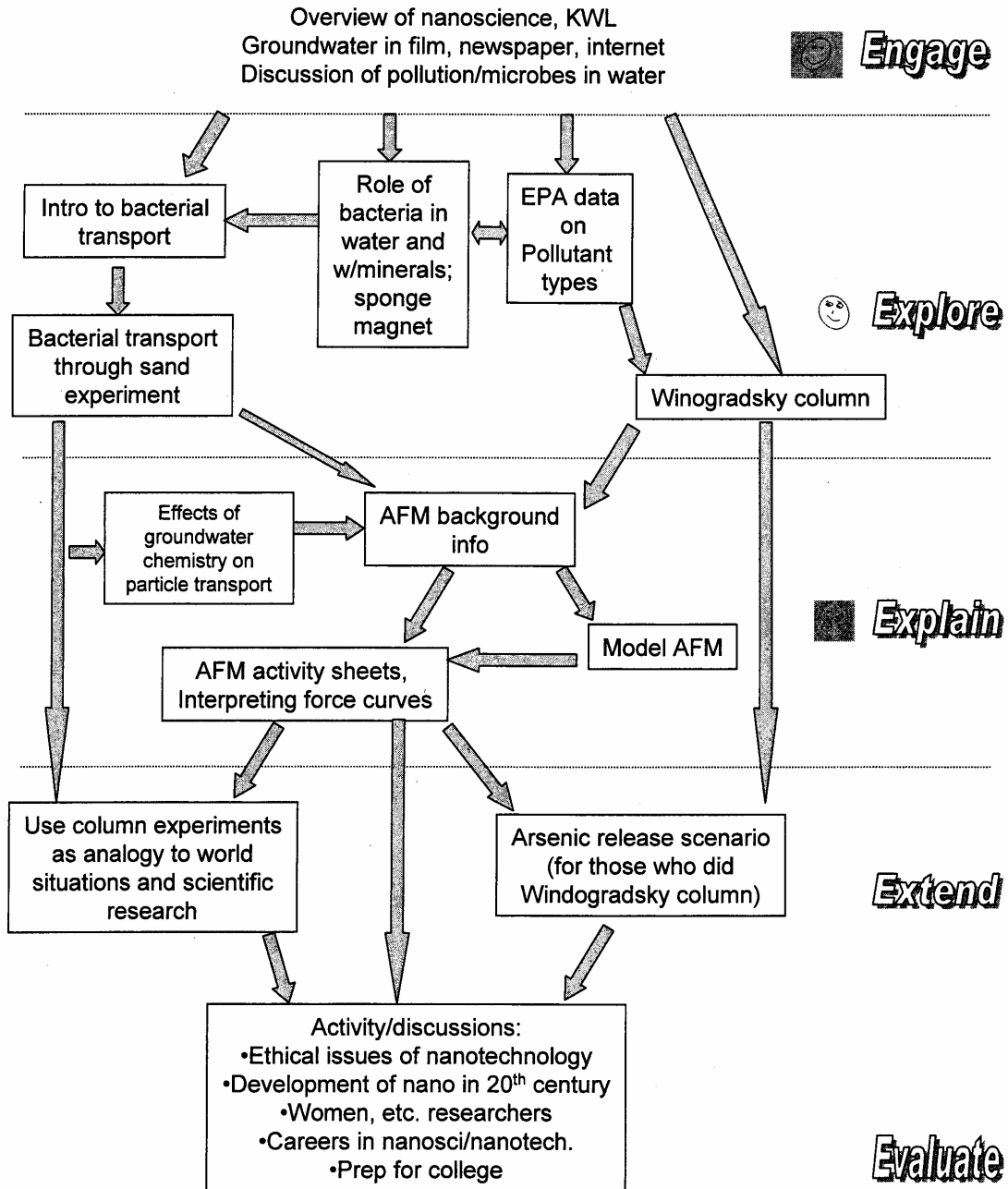
Graphing utilities (graphing calculators or computer graphing simulators) will be used by students and teachers. Graphing utilities enhance the understanding of realistic applications through modeling and aid in the investigation of trigonometric functions and their inverses. They also provide a powerful tool for solving/verifying trigonometric equations and inequalities. Any other technology that will enhance student learning should be used if available.

- T.1 The student will use the definitions of the six trigonometric functions to find the sine, cosine, tangent, cotangent, secant, and cosecant of an angle in standard position, given a point, other than the origin, on the terminal side of the angle. Circular function definitions will be connected with trigonometric function definitions.
- T.2 The student, given the value of one trigonometric function, will find the values of the other trigonometric functions. Properties of the unit circle and definitions of circular functions will be applied.
- T.3 The student will find the values of the trigonometric functions of the special angles and their related angles as found in the unit circle without the aid of a calculating utility. This will include converting radians to degrees and vice versa.
- T.4 The student will use a calculator to find the value of any trigonometric function and inverse trigonometric function.
- T.5 The student will verify basic trigonometric identities and make substitutions using the basic identities.
- T.6 The student, given one of the six trigonometric functions in standard form (e.g., $y = A \sin (Bx + C) + D$, where A, B, C, and D are real numbers), will
 - * state the domain and the range of the function;

* determine the amplitude, period, phase shift, and vertical shift; and
* sketch the graph of the function by using transformations for at least a one-period interval.
The graphing calculator will be used to investigate the effect of changing A, B, C, and D on the graph of a trigonometric function.

- T.7 The student will identify the domain and range of the inverse trigonometric functions and recognize the graph of these functions. Restrictions on the domains of the inverse trigonometric functions will be included.
- T.8 The student will solve trigonometric equations that include both infinite solutions and restricted domain solutions and solve basic trigonometric inequalities. Graphing utilities will be used to solve equations, to check for reasonableness of results, and to verify algebraic solutions.
- T.9 The student will identify, create, and solve practical problems involving triangles and vectors. Techniques will include using the trigonometric functions, the Pythagorean Theorem, the Law of Sines, and the Law of Cosines.

Appendix E: SAMPLE LESSON PLAN DRAFT



Appendix F: ACRONYMS

AFM	Atomic Force Microscopy
ANT	Actor Network Theory
ASPIRES	A Support Program for Innovation Research Strategies
BES	Basic Engineering Sciences
BECON	Bioengineering Consortium
BFM	Biological Force Microscopy
CALTECH	California Institute of Technology
CBEN	Center for Biological & Environmental Nanotechnology
CD	Compact Disk
CNI	Carbon Nanotechnologies
CRC	Corporate Research Center
DOD	Department of Defense
DOE	Department of Education
DARPA	Defense Advanced Research Projects Agency
DOJ	Department of Justice
EPA	Environmental Protection Agency
EPOR	Empirical Programme of Relativism
ESEA	Elementary & Secondary Education Act
FY	Fiscal Year
GAANN	Graduate Assistance in Areas of National Need
GSA	Geological Sciences Association
IBM	International Business Machines Corporation
IIT	Indian Institute of Technology
IRB	Institutional Review Board
IWGN	Interagency Working Group on Nanoscience, Engineering & Technology
KRB	Kellog, Brown & Root
KWL	Know, Wonder, Learn
MEND	Mine Environment Neutral Drainage
MIT	Massachusetts Institute of Technology
MNT	Micro Nanotechnology
NASA	National Aeronautics & Space Administration
NCDP	Nanotechnology Curriculum Development Project
NCLB	No Child Left Behind
NCNI	Northern California Nanotechnology Initiative

Appendix F: ACRONYMS Cont'd

NER	Nanoscale Exploratory Research
NIH	National Institute of Health
NIRT	Nanoscale Interdisciplinary Research Teams
NIST	National Institute of Standards & Technology
NNI	National Nanotechnology Initiative
NSE	Nanoscale Science & Engineering
NSET	Nanoscale Science, Engineering & Technology
NSF	National Science Foundation
NSRC	Nanoscale Science Research Center
NSTC	National Science & Technology Council
OSTP	Office of Science and Technology Policy
PI	Principal Investigator
R&D	Research & Development
SCOT	Social Construction of Technology
SEM	Scanning Electron Microscopy
SOL	Standards of Learning
SSK	Sociology of Scientific Knowledge
STM	Scanning Tunneling Microscopy
STS	Science & Technology Studies; Science Studies
UK	United Kingdom
US	United States
USDA	Department of Agriculture
UVA	University of Virginia
VAST	Virginia Association for Science Teachers