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WILL *PREY* CONSUME NANOTECHNOLOGY?

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Abstract

Perceptions of nanotechnology and possible repercussions are explored. A short survey was conducted to gather data, and a summary of the technology as it stands today is presented. Nanotechnology in medical, materials, and manufacturing applications are presented and perceptions of the benefits and threats. It is important for scientists to understand how the public perceives their technology, so that they can help people understand nanotechnology better. In this, very little is known by the public, so there are unfounded fears.

Table of Contents

List of Figures

List of Tables

Introduction and Background Information

Nanotechnology is a new and rapidly growing technology that is currently defined in two ways. A broad definition of nanotechnology is any material or device that has a dimension less than one micron in length (a micron is one millionth of a meter [10^{-6}]). A more restrictive definition from the Patent Office states that it must have one dimension between 1 – 100 nanometers (a nanometer is one billionth of a meter [10^{-9}]) and that the small size must be essential to the functionality of the device.

This project tried to assess, collect, and survey positive and negative attitudes towards nanotechnology. Because nanotechnology is a new science that is not understood by all, some people fear that it will create undesirable effects. These effects include the prospect of grey/green goo, environmental risks, and health risks, which are later explained (see Appendix C for a comprehensive list of fears). We examined the general perceptions of the public with respect to nanotechnology. The discussion focuses on nanotechnology in the following three categories: manufacturing, materials, and health and nano-doctoring.

The impetus of the project is the necessity to understand how the public views nanotechnology. A growing number of patents in the United States (see Appedix F for patent trend information), combined with a projection of $982 million being spent in fiscal year 2005 (see Appendix E for financial data), demonstrate a need to examine these perceptions. This project will allow scientists in the field to better understand how their work is being perceived by the nonscientific community. Using research through popular literature, online articles and blogs, books, and a student survey, we will discuss what the perceptions of nanotechnology are like today.

This report is organized into four sections: Background Information, Data Analysis, Summary and Recommendations, and Appendices. The Background Information section provides a view of current issues, applications and advancements of the three categories. The Data Analysis section is an examination of data collected from the survey, books, and internet sources. The Summary and Recommendations section is a discussion of the results and recommendations for future projects and the scientific community. The Appendices include raw data from the research and survey.

Medical Background

In the coming years, nanotechnology and medical science will almost assuredly merge to produce some exciting applications which will render current medical devices and techniques obsolete. This utilization of molecular manufacturing –"the production of complex structures via non-biological mechano-synthesis (Pheonix 2005)"– to create nanoscale devices that can assist or replace current methods for drug delivery, surgery, tissue repair, and other medical techniques is known as "nano-doctoring", and it has already produced some exciting discoveries in recent years (Mohan 2004).

The vision for the future of nano-doctoring is one that foresees "hospitals without walls" (Mohan 2004), or the ability of a person's own body to become a self-sustaining hospital that can automatically treat any affliction. There are four main subcategories to the science of nano-doctoring. They are biophotonics, biosensors, medical nanobots, and drug delivery. Biophotonics deals with the creation of imaging devices at the nanoscale that could be inserted into a patient's body. Biosensors involve the development of "bio-tags" at the nanoscale level that can track the location of proteins and other biological molecules that might be associated with viruses or diseases. Medical nanobots are mechanical robots created at the nanoscale that could potentially be used to repair tissue damage, trigger neurons for muscle stimulation, and other medical procedures. Drug delivery and nanotechnology can be combined in order to allow for the release of drugs inside a patient's body, thus eliminating the need for pills and other forms of external drug delivery (Mohan 2004).

In early 2004, microengineer Carlos Montemagno and his team of scientists at UCLA developed the world's first functional muscle-powered nanobot. This silicon nanobot is only half the width of a human hair and has begun to move around in a Petri dish due to the contraction of living cardiac muscle tissue attached to its underside (Pease 2005).

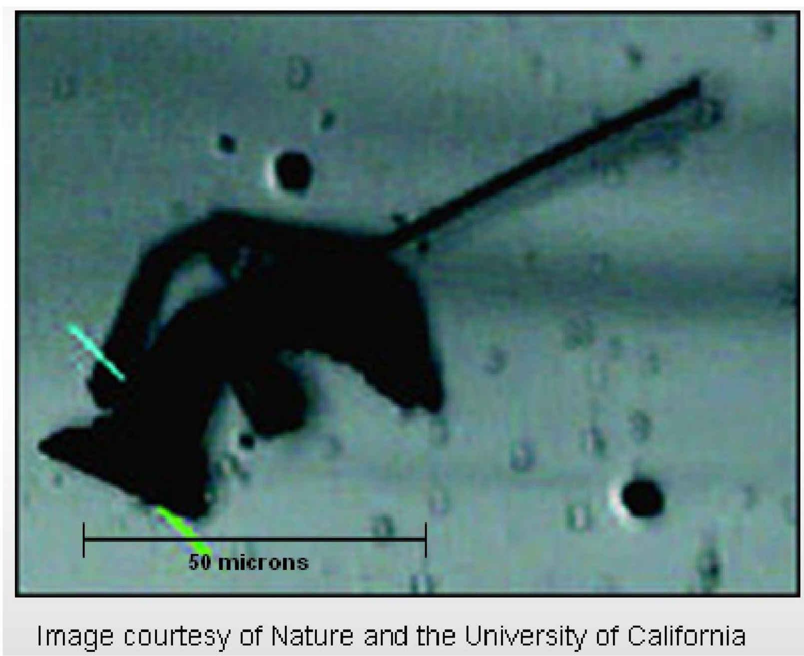

Figure 01. Cardiac muscle-powered nanobot

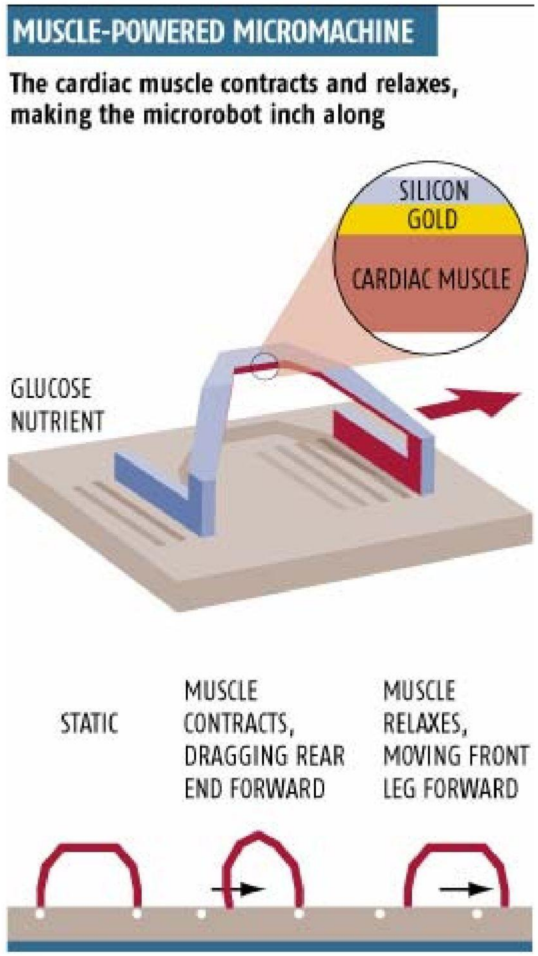

Figure 02. Cardiac muscle-powered nanobot, schematic diagram
(www.newscientist.com 2004)

To create this nanobot, Montemagno and his team etched away the coating on the underside of a silicon arch in order to deposit gold film which naturally attracts the growth of muscle cells. In order to achieve muscle tissue growth on the arch, living cardiac muscle tissue from rats was placed in a Petri dish with a glucose culture medium. A restricting beam held the arch in place in order to restrict movement of the partially formed nanobot until complete growth of the cardiac tissue was observed along the length of the arch. Upon removal of the restricting beam, the nanobot immediately started to crawl along at rates upwards of 40 μm per second (Ananthaswamy 2005).

Muscle-powered nanobots, such as the one created by Montemagno and his team, offer an alternative to current MEMS (micro-electromechanical systems) that are powered by electricity, which is difficult to continuously provide. Muscle-powered nanobots could use the body's own bloodstream to obtain glucose for the contraction of the cardiac muscle tissue and subsequent movement of the nanobots throughout the body.

The potential that this technology has for the future of medicine is exciting, to say the least. Muscle-powered nanobots could be used to stimulate nerves in paralysis victims who have suffered phrenic nerve damage and thus can not excite the contraction of the diaphragm muscles in their bodies. These patients currently rely on respirators in order to provide oxygen to their circulatory systems. With the development of muscle-powered nanobots in cooperation with piezoelectric devices (devices which provide a conversion between mechanical and electrical energy), paralysis victims could finally breathe without the aid of respirators. In addition to this application, muscle-powered nanobots could be used to repair meteorite damage to spacecraft, provided there is sufficient glucose present. The size of these nanobots renders them capable of filling in meteorite-sized breaches in the hulls of a spacecraft.

Drug delivery at the nanoscale level is one of the most researched aspects of nanotechnology today. Potentially, this technology could be used to automatically release medication in a patient's body when needed. The technology revolves around the use of nano-particulates, which are particles that have diameters of less than 100 nm. The two major nano-particulates presently involved in nanoscale drug delivery systems are nanoscale pockets and nano-sphere hydrogels. Nanoscale pockets are nano-particulates that release pulses of a drug as the material dissolves. Nano-sphere hydrogels are "stable, organic materials that swell at a rate that is dependent on the acidity of their environment" and are created at the nanoscale (Dubin 2).

Another type of nano-particulate that is involved in nano-doctoring is known as the quantum dot. Quantum dots have diameters smaller than the wavelength of visible light and can be used as bio-tagging molecules due to their unique size and physical properties; for example their luminescence under ultraviolet light. The size of the quantum dot controls the color that will appear under ultraviolet exposure. Quantum dots can be used in the early detection of diseases. Dots are tagged to specific proteins enabling concentrations of a specific protein or DNA sequence to be monitored. An abrupt change in the concentration of a protein in certain cells may be an early sign of cancer, and quantum dot bio-tagging can accurately and efficiently detect these changes.

Materials Background

The field of nanotechnology has many applications in the materials realm. Included under this umbrella term are consumer products ranging from cosmetics to car parts and beyond. Carbon nanotubes are one of the better known and currently more used applications of nanotechnology. They are long chains of carbon particles put together in a way that creates one of the strongest materials currently known. They can be thought of as a one particle thick sheet of graphite rolled into a cylinder. They are about 1.4-1.6 nm in diameter and can be assembled to as long as about four centimeters, which is amazing considering how large this length to width ratio is, as well as the fact that they still retain such strength. They can also be found in concentric cylindrical shapes, where one nanotube is contained within another slightly larger nanotube; an image of the concentric setup is shown in the figure below.

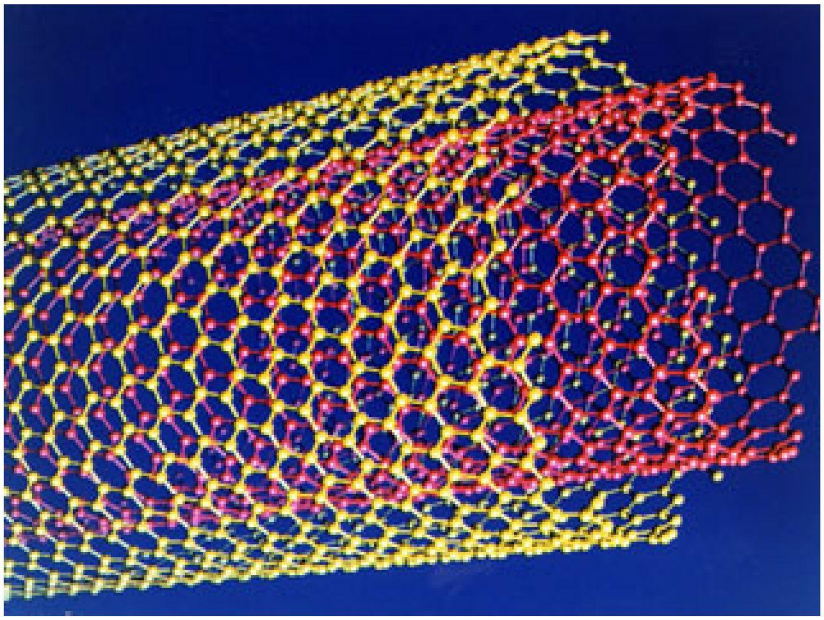

Figure 03. Concentric carbon nanotubes (www.nec.com)

They have 100 times the strength of steel at one-sixth of the weight and the same rigidity as diamond.

Currently nanotubes can be found in sports equipment such as tennis rackets, where they are used in the making of the handle to give players more control over their swing, and to give the racket more of a snapping action (www.bizjournals.com 11/29/02). In the medical field, the nanotube is perfect for many possible medical applications, such as drug delivery systems. A nanotube could theoretically be filled with a drug, and then by capping the ends of the tube, effectively be turned into a drug capsule. The caps could be designed to dissolve at specific rates, or to release the drugs when they come into contact with a certain substance in the desired affected area. Alternatively, the idea of creating nano-sized syringes using the nanotubes has also been explored. This would give doctors an enormous advantage being able to inject a drug or some kind of treatment in a much more specific and localized fashion Also then in a very basic application, they can be used as nano-sized test tubes, whereby capping one end you can create a tube.

Cosmetic companies have begun to use nanotechnology in their products as well. Certain particles have been added to two major cosmetic companies' face creams in order to help skin moisturizers penetrate deeper into the applicant's skin, thereby increasing the effectiveness of their products. Nanoscale iron oxide particles have been used as pigment in the lipstick and hair dye of other companies. The particles help the color to retain its strength and stay longer. Titanium oxide and zinc oxide particles are also being used in sunscreen. These two particles are ideal for blocking the sun's harmful rays, because they have incredible reflective properties, and when applied to the skin, are invisible to the naked eye (www.ngimat.com 2005).

Car companies are using nano-particles in cars because of their unique properties. The particles are stronger and more lightweight than current materials, so in vehicles such as the Hummer, where gas mileage is a large issue, these new applications are advantageous (www.detnews.com 11/28/04). By lightening the weight of the car that the engine constantly must move, you reduce the amount of gas constantly utilized. Because the particles are stronger, they also have the added advantage of providing additional safety to the drivers. Large clothing companies now use molecular structuring (an application of nanotechnology) to create stain-resistant clothes. The particles effectively create a protective matrix between the fibers of the cloth so that stain particles cannot penetrate in between the fibers of the material and become stuck there.

Electronics have been revolutionized by the applications of nanotechnology. Computer chips have components built on the nanoscale. New research is also being conducted in the area of memory advancement, which is trying to utilize the nanoscale mechanics to create new computer memory devices that will hold much more information in a much smaller space. Appendix C contains an extensive list of current applications.

Manufacturing Background

Since nanotechnology is a relatively new field, manufacturing techniques and processes are in their infancy. There are two general approaches to manufacturing, a top-down and bottom-up approach. There are issues with these techniques, and they have a long way to go before their full development occurs.

The bottom-up approach implies that scientists will be able to manipulate individual atoms to form structures. This means that a technique to grab individual atoms and move them to desired positions needs to be developed. In 1990, IBM researchers proved that this was possible by positioning 35 xenon atoms on the surface of a nickel crystal, spelling "IBM". After developing the technique to reposition individual atoms, scientists will be ready to work with nano-sized (or nano-scopic) machines. The next step will be to develop assemblers, which can be programmed to manipulate atoms at will. Trillions of assemblers will be required to make materials on a practical time scale. In order to create enough assemblers to build consumer goods, replicators (nano-scopic machines programmed to build more assemblers) will need to be produced.

The second approach to nano-sized manufacturing techniques is top-down synthesis. This approach of production means that scientists take normal sized products and shrink them down as much as possible. Currently, the electronics industry has seen many applications of this approach, particularly to computer components. The Intel Pentium IV (tm) processor currently has a gate size of 90 nm. Intel has been maintaining Moore's Law (the idea introduced by Gordon Moore in 1965 that the number of transistors will double every few years), with its incredible advances in processors. Despite these amazing advances, this does not fit the Patent Office's definition of nanotechnology. The advances in using this method have not yet been applied to the *function* of goods and materials, but only to the *performance* of these products.

One of the manufacturing problems is the fact that everything is so small. How do you grab the smallest building block and move it? Imagine a giant attempting to pick up and stack amoeba. Another issue is sustainability of a system under normal conditions. The force of your breath alone is enough to completely destroy an entire nano-scopic system or at least displace it. Scanning and imaging on such a small scale is currently difficult enough of a problem to solve. Atomic Force Microscopy was invented by IBM in 1986;

> it uses a ceramic or semiconductor tip one atom wide positioned at the end of a cantilevered bar. As the tip is moved over the material, it either continuously touches or periodically taps the surface and bends as it is repelled or attracted to the structure. A laser picks up the deflections (http://www.answers.com April 5 2005).

Unfortunately, this means that AFM's are dependent upon the shape of the individual tip, making it a complicated process to get exact readings from.

In addition to complications with manufacturing techniques, there are many serious environmental concerns with regard to nanotechnology. This project attempts to address some of these concerns, and to find out how the general populace understands nanotechnology. One concern is the idea of grey goo, which is the idea that nanobots might get out of control and convert the planet and every living thing on it to a uniform but useless mass of bits and pieces. This idea has been presented many times over in science fiction works, including Micheal Crichton's recent work *Prey*. In *Prey*, Crichton introduces the idea that swarms of nanobots become a sort of predator that feed off of humans and other creatures. Similar speculations, such as that presented in Isaac Asimov's *Fantastic Voyage,* introduce the idea of miniaturization, where a highly specialized crew of people are shrunk inside an exploration vessel, and inserted into a scientist's body in order to save his life.

Prominent scientists such as Richard Smalley do not have an optimistic outlook (Bainbridge March 2001). Scientists sharing Smalley's opinion believe that there is a certain limit to which one can build. One theory that describes this idea is the uncertainty principle, which states that it is impossible to know precisely the position and velocity of any particle simultaneously at any one moment in time (Newton 2002). Another theory is that "the natural motion of atoms and molecules is sufficiently great that structures built by means of nanotechnology processes would not remain stable" (Newton 2002).

Some political leaders, such as Pat Mooney, have a pessimistic outlook on the future of nanotechnology (www.nanotec.org.uk). Unlike the scientists, Mooney and his supporters dislike the prospect of nanotechnology, not for scientific purposes, but rather for political reasoning. They focus on ideas such as the grey goo theory, and gain support through spreading fear to the public. Grey goo is the theory that control over nanotechnology, specifically nanobots, will be lost and turn the planet into a mass of biological waste. Other potential threats politicians discuss are related to new technology fear – people being replaced by machines, hazards of releasing nano-particles into the environment, and other related topics.

Analysis of *Prey*

As nanotechnology becomes better known, it has been finding its way into popular culture by means of comics, cartoons, and fiction novels. Most notable of these is Michael Crichton's novel *Prey*. The original idea behind this project was brought up by the fear that this novel would cause excessive worries to arise among the population, thereby diminishing the willingness of people to fund and consume nanotechnology and nanotechnology products.

Through his novel, Crichton introduces the idea of grey goo; the possibility that nanobots could go out of control and reproduce uncontrollably and take over the world. He also goes so far as to introduce the idea that nanobots could possible interface with and control human beings. The nanobots in the novel start out as a project to try and create an easily hidden and controllable surveillance system for military as well as medical uses. The idea was that a swarm of nanobots would function as a hive, and therefore be able to adapt to their surroundings and obstructions while still working towards their main goal. Obviously, for the sake of the novel, things do not go right, a few swarms go out of control, one manipulating the humans, while others begin reproducing and attacking animals and eventually humans. The entire problem of the out-of-control nanobots was caused by the scientists, who were unable to make the swarm function in an uncontrolled environment, and so they released them into the desert. Then of course, they went out of control. At the end, the main character worries that a mistake such as this will be the end of the human race, where for the sake of new science, unwittingly scientists could bring about a manmade apocalypse.

These issues are extremely frightening, even to someone that is knowledgeable in the field of nanotechnology. A grey goo scenario could arise, if precautions are not taken in the handling and development of nanotechnology. The introduction to the book gives a brief scientific background to the field of nanotechnology, and discusses some of the current applications and how far along the technology is. He says (with backup from Eric Drexler), "Even by the most optimistic (or dire) predictions, such organisms [nanobots] are probably decades into our future (Crichton 2002)." Then he goes on to say that by that time we should have "international controls for self-reproducing technologies" and that their enforcement will be stringent. But, he then plants the seed of doubt by ending the introduction with "[the possibility] that someone will manage to create artificial, self-reproducing organisms far sooner than anyone expected. If so, it is difficult to anticipate what the consequences might be (Crichton 2002)." Crichton is playing the devil's advocate, by giving the scientific truth, and then immediately planting the seed of doubt as a segway into his novel.

Data Analysis

Methodology

Since nanotechnology is a relatively new field, information relating society to the technology is sparse. The background information is based on general data concerning nanotechnology from the National Science Foundation (NSF), certain books (listed in the References section), as well as online forums and news sites for up-to-date information. The original plan was to include data generated from the WPI Technology Confidence Index (TCI), but the data were unavailable due to time constraints. The TCI is a "quarterly poll of a nationally representative sample of adults living in the US (www.wpi.edu/News/TCI/About 12/08/04)." Although the data were not available for this project, it will be available for inclusion in subsequent reports. A small survey was taken in place of the TCI data.

The survey was conducted mainly throughout WPI and included five off-campus sources: Clark University, Bryant University, the Massachusetts Institute of Technology, Merrimack College, and acquaintances of the project members. The purpose was to collect data on people's knowledge of nanotechnology, their opinions of it, and their thoughts on the threat it might pose as an emerging field. In total, 53 people were surveyed, of whom sixteen had non-scientific backgrounds, and 37 had scientific backgrounds.

The survey is a short list of sixteen statements that corresponded to general knowledge of the technology, medical applications, material applications, and manufacturing applications. The people taking the survey were asked to rate the statements by their agreement or disagreement with each one. The rating was based upon the following scaling system: 0 - I do not know enough to answer this question; 1 - Strongly Disagree; 2 - Disagree; 3 - Neutral; 4 - Agree; 5 - Strongly Agree. The survey in its entirety is included in Appendix A.

Books and Studies

In addition to the survey conducted, outside sources, including an overview of studies, books, and internet polls on nanotechnology, were examined. In 2003, the United Kingdom's Royal Society and Royal Academy of Engineering Nanotechnology Working Group contracted out to the BMRB Social Research company to conduct research on the public awareness and knowledge of nanotechnology in the UK They polled just over one thousand people and broke down their responses into multiple demographics, including age, gender, and socio-economic level. The vast majority of people -almost 70 percent- all thought that nanotechnology would have positive affects on the future. Despite this resounding support, about another 24 percent were unsure of what they thought nanotechnology would hold for the future. These percentages are slightly misleading though. Of the one thousand people polled, only about two hundred ninety people had heard of nanotechnology, and only about one hundred ninety people were able to give some kind of a definition. This lends itself to one of the problems that the WPI survey ran into, there are plenty of people willing to take the survey, but not nearly enough of them have any knowledge of nanotechnology, even a large number of the engineers that were polled in the WPI survey did not have a clear understanding of nanotechnology or its applications.

In 2004, Christopher P. Toumey of the University of South Carolina (USC) coordinated a similar study. His group polled, educated, and questioned forty-four people on nanotechnology. They ran a six week program with speakers from USC's departments of Philosophy, Chemistry, the Medical School, English, and the NanoCenter. Although this report does not have good quantitative data to analyze, it does have a lot of qualitative data. This study saw a distinct increase in the participants' confidence in understanding the scientific and societal implications of nanotechnology at the completion of their program, which is indirectly consistent with other data we have gathered.

In our internet research on nano-related websites, we came across several polls. In The Zogby International/Forbes ASAP Poll (in 2000), 33.2% of the 1,021 people surveyed said that they would very likely use microscopic computers floating through your body that would detect disease or injury immediately. A poll conducted on www.nanodot.com on *Prey* had some interesting results. The survey essentially asked 'What do you think of grey goo?' 27% of the 444 who responded said that it's a problem for the field. 23% believe that not a problem; people know fiction isn't technically accurate. 36% said it's a good thing: the idea that advanced nanotechnology has dangers will be planted and 13% said that they weren't sure. Although certain assumptions have to be made about the participants in these studies, the data from them follows the data found in the studies and books that we read.

We found *Recent Advances and Issues in Molecular Nanotechnology, Nanotechnology basic science and emerging technologies,* and *Nanocosm* to be helpful learning about current nanotechnology theory. They provide good background information, as well as clues as to where to look for polling data. They also contain insight into the debate among scientists about the future of nanotechnology.

Clearly, this shows that there is a total overall lack of publicizing of nanotechnology. This is not to say that there should be billboards with models proclaiming the wonders of nanotechnology, far from it, but information should not be written about in science and technology magazines that few people read. A great deal of people could be persuaded to take interest in the field, which is important, since people tend to fear things that they do not understand. So if it were possible to educate people at the same time as introducing them about the technology that would be the most desirable course of action.

Analysis of General Survey Questions

General questions are included at the beginning of the survey in order to gain some idea about the knowledge and comfort level of the respondents regarding nanotechnology. Responses to these introductory questions were expected to be around neutral or below that level on average considering nanotechnology is not a topic that is widely taught and most people probably have not heard of it.

The first question which dealt with the respondent's knowledge of nanotechnology averaged around a 2.75 on our scale system of responses. This suggests that the respondents, on average, did not know anything about nanotechnology or could only form a rough definition of what it is. The results for this question were found to confirm the original hypothesis that the population as a whole has only a limited understanding of nanotechnology.

The final two questions of the general survey question section concerned the comfort level of the respondents with respect to nanotechnology directly affecting them or becoming widespread across society. The average of the responses for these two questions was approximately 3.3, which was slightly above expectations. Because of their limited knowledge, it was expected that people would not be positive. The results revealed that, although respondents had only minimal knowledge of what nanotechnology is, they seemed to feel slightly comfortable with it becoming a part of their lifestyles.

Medical Data Analysis

Prior to the collection of the survey data, it was assumed that the medical data would prove to be among the most positive responses to all the survey questions. This was based on the hypothesis that, when it comes to potentially fatal afflictions, the majority of the population would opt for the newest and most effective treatment rather than an older, less effective method, even if this newer treatment has not been thoroughly tested yet. The resulting data supported this hypothesis as the medical responses were among the most positive of all of the survey questions.

The first three questions of the medical section, which concerned the assistance of nanotechnology with necessary bodily functions, drug delivery, and as an alternative to stem cell research, had an average of around 3.5, which would place it in between "neutral" and "agree" in our scale system of responses. Looking back at the section of the survey that dealt with general questions, one can see that the average response for question one ("I would rate myself as being knowledgeable on the topic of

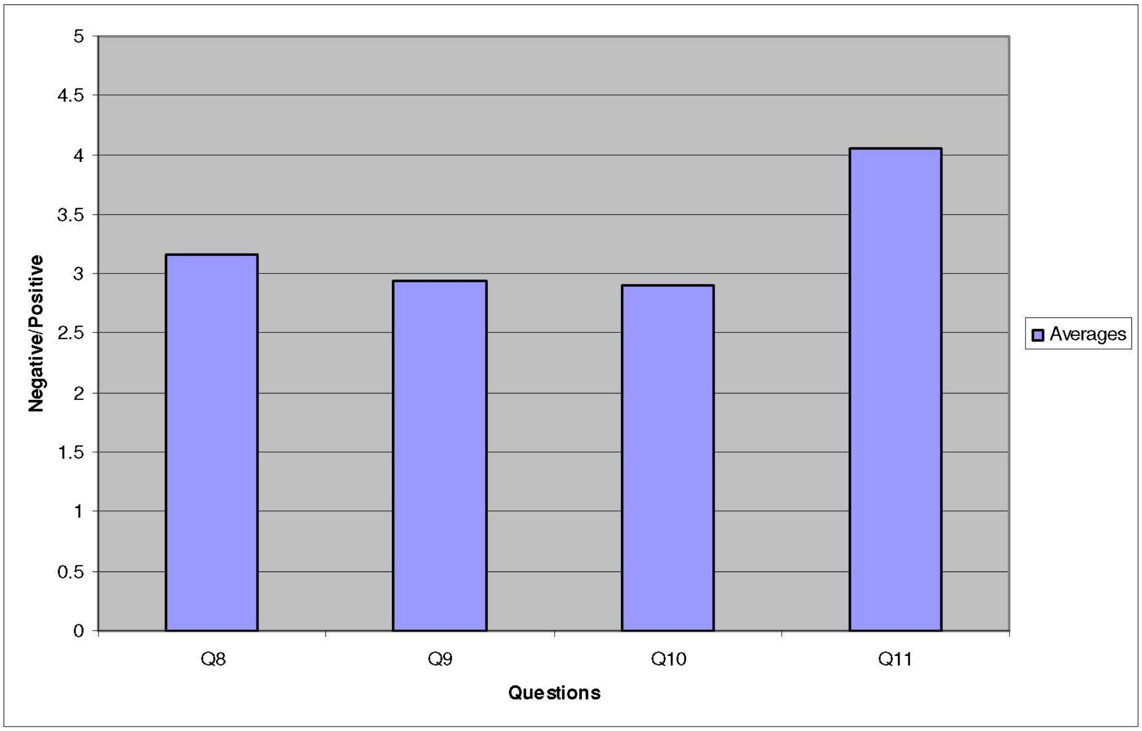

Figure 04. Average medical survey responses

nanotechnology.") was around 2.75, showing that most people had not been informed of nanotechnology and had only limited understandings of what nanotechnology is. This fact, coupled with the mostly positive responses to the first three questions of the medical section of the survey, shows that most people tend to support newer and more effective methods of treatment, even if they have little knowledge about how it works.

The most positive average responses for the medical section of the survey came from the fourth and final question. This question dealt with the use of nanotechnology to help repair nerve damage in paralysis victims. The average of the responses for this question was around 4.4, which shows that most people who took the survey seem to feel that this would be a better alternative to current treatment for paralysis victims. This question was concerned with arguably the most potentially fatal of the afflictions mentioned in the medical questions and thus it complies with the initial hypothesis that was formed before the survey took place.

Dividing the responses into scientific and non-scientific background categories, results in the following graph.

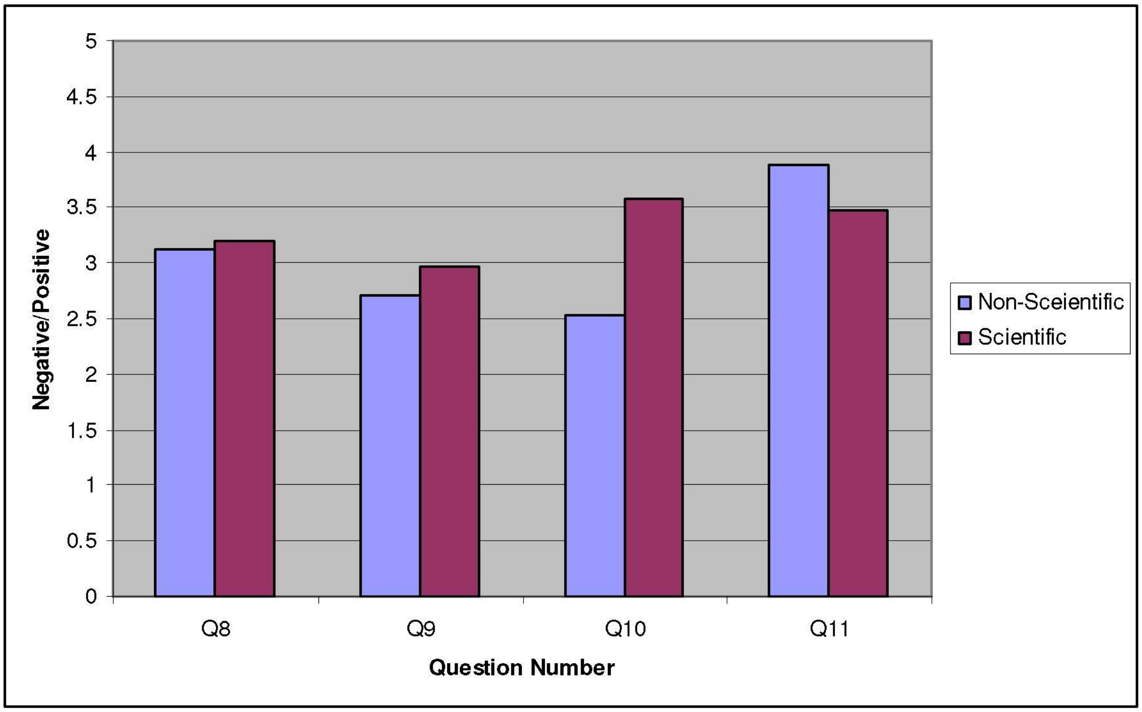

Figure 05. Medical response comparisons

One can see that for each question those with scientific backgrounds responded with an average rating that was more positive than the responses of those with non-scientific backgrounds. This suggests that people of scientific backgrounds tend to have more optimistic outlooks towards newer technology than those with non-scientific backgrounds.

Materials Data Analysis

From the data gathered in our WPI based survey, the area of nano-materials has a positive perception. Just over 50% of the people surveyed in our survey had no negative views on the field. The following graph shows the average response for each of the five materials questions, which can be found in Appendix A. The only question that had a more negative response was the question regarding nanotechnology in cosmetics, and the low average is due to the fact that roughly 25% of those surveyed felt that they did not know enough about it to answer. Without answers the average response becomes 3.37, meaning people are more positive than negative, be it only slightly.

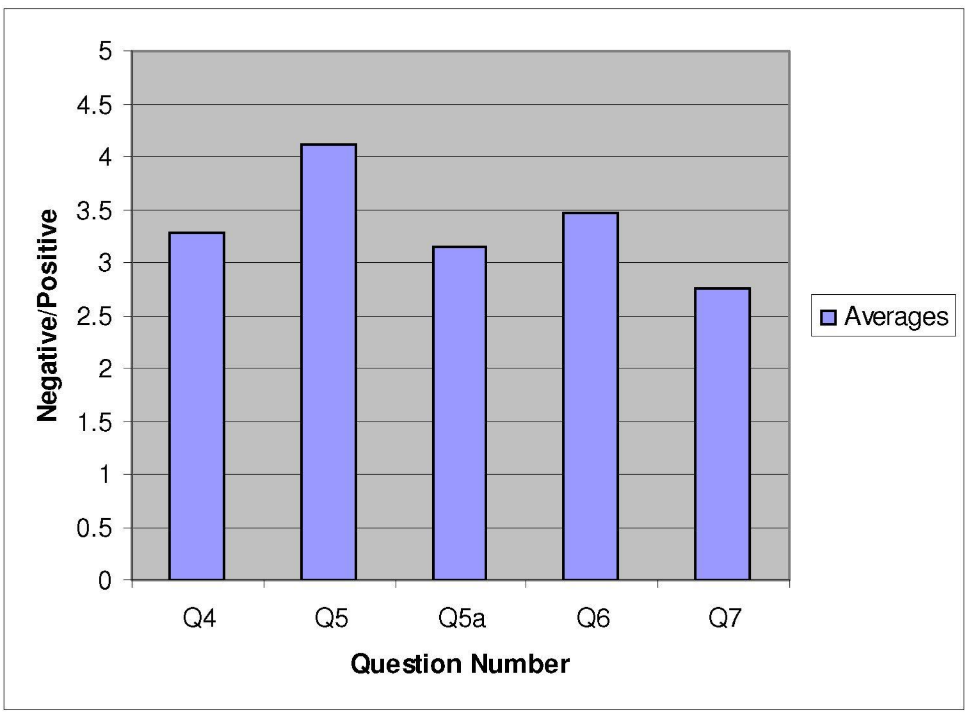

Figure 06. Average materials survey responses

Although there were a few people who were completely unaware of the involvement of nanotechnology in some everyday objects, they were not opposed to using them now that they had been informed. When asked about their willingness to use passive forms of nanotechnology, the resounding response was very positive, only five percent said that they did not feel comfortable with the idea. This bodes well for the continuation of nanotechnology-based improvements in people's everyday lives.

For the most part, there is a positive outlook on more active forms of nanotechnology; however about 18% of the people surveyed were strongly against it, but at the same time, only about 7% said that they were completely comfortable. Along the same lines, opinions of cosmetic uses of nanotechnology is somewhat spread out, no one was strongly opposed, but no one was completely trusting. The ambiguous stance that people seem to have is not necessarily a bad thing, because it signals that people are questioning new technologies and not just accepting or denouncing them blindly. This skepticism is good for a few reasons; mainly it shows that people are not becoming overwhelmed by all the recent technological advances, they understand that these advances are important and could have a large affect on their lives.

Over 90% of the sample population is more than comfortable with nanotechnology in their everyday objects, and this brings up an interesting point. Less than half of the people answering the survey knew that nanotechnology was involved in clothes, sports equipment, cosmetics, and cars, among other things, but having been "enlightened" to the fact, they said will not be deterred them from using such products in the future. This raises the question of whether people are more open to the idea because they realized that they have been using nanotechnology in ways that they had never before considered and can see that there is nothing to worry about, or is it that they already felt no compulsion to fear nanotechnology. Since it seems that people are relatively optimistic about future nanotechnological developments, then they most likely are not wary of nanotechnology in the first place, which means that on a certain level, people are not horribly bothered by the prospect of nanotechnology becoming more widely known and used.

Of the population surveyed, a great difference does not exist between the opinions of scientifically oriented people and those who are not. The following graph plots the averages of their responses; the left column of each pair is from non-scientific people, and the right one is from scientific. As you can see, for questions 4, 6, and 7, the responses are for the most part very similar, whereas for question 5 and 5a, the scientifically minded people are much more positively opinioned. Question 5 asks if the person would be comfortable using products that contain passive forms of nanotechnology, and question 5a asks the same about products with more active forms of nanotechnology.

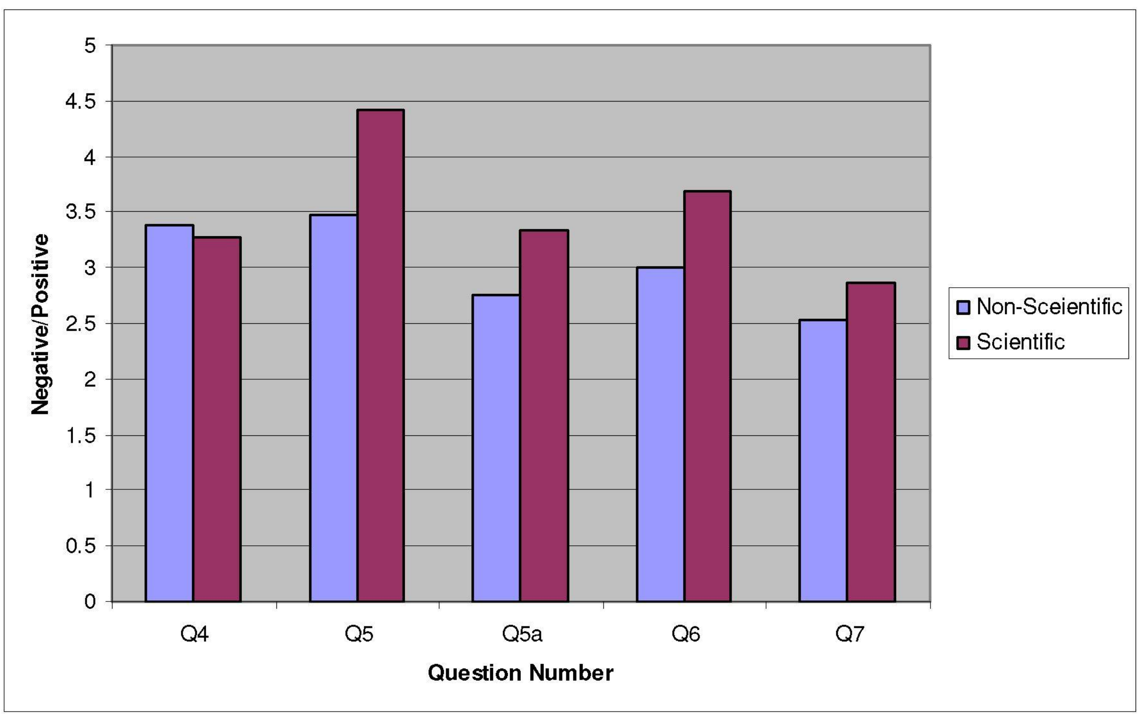

Figure 07. Materials responses comparisons

The differences in the responses for these two questions definitely have some correlation to what type of background the people have. It is impossible to say that there is a definite causal relationship, but the non-scientific people are just overall less willing to trust the new technology. This could be because scientific people learn a great deal of their knowledge through experimentation, and see the prospect of using these new products as a kind of new experiment. In either case, the differences are apparent, without being severe, which is good because that means that the scientific circle is not too separated from the general public.

Manufacturing Data Analysis

It is difficult to discuss applications of nanotechnology with relation to manufacturing processes, as they hardly exist. However, the survey we have conducted, combined with recent advances and issues, are good guidelines for what the future may hold.

The survey we conducted, composed of 37 WPI community members and sixteen people of non-scientific backgrounds, yielded some interesting results. Four of the survey questions directly relate to manufacturing. A statistical analysis of the data generated some trends from the manufacturing questions. One such trend indicates that people are comfortable with nanotechnology applications to manufacturing processes. A workplace involving particles on the nano-scale, as well as the release of nano-particles into the environment are both shown to be acceptable. Responses also show that people felt that nanotechnology would not be more dangerous for the environment than current manufacturing techniques.

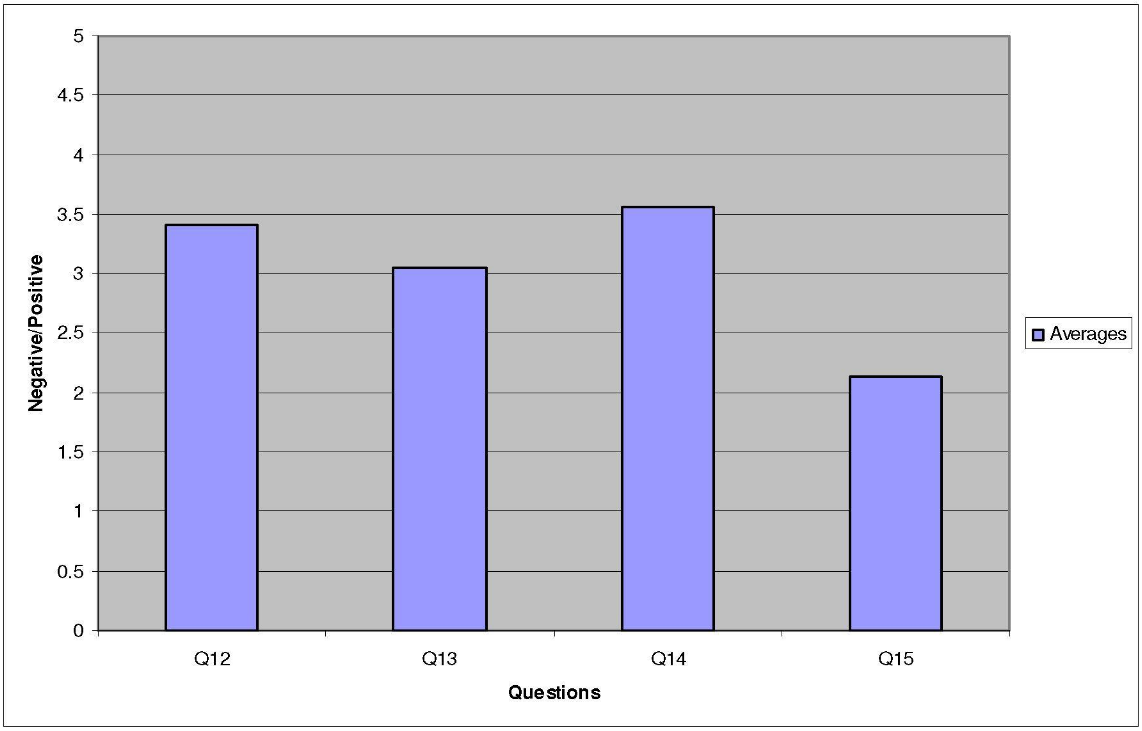

Figure 08. Average manufacturing survey responses

The means of the responses are shown in the above chart. As you can see, the responses are not strongly positive or negative. We can indirectly infer that people are aware of some current nanotechnology applications through responses to Q14 (mean 3.534). One trend that stands out is that although manufacturing of nano-products and nano-materials (see Materials Section), as well as working in an environment where these are created (Q12 mean 3.372), are acceptable, references to self-replication (Q15 mean 2.116 mode 2) are not liked, but not strongly disliked as we learn from examining the mode (see table in Appendix B for response data table). The data for the question on self-replication shows that people have a dislike for the idea of nanobots controlling their own reproduction. Figure 9 shows that there is a negligible difference of opinion between people who have scientific and non-scientific backgrounds. Several possible reasons for this dislike exist. Among them, a fear from the science fiction community, perhaps related to grey goo theory, or fear associated with new technological developments. Another possibility is the discrepancy from the scientific community.

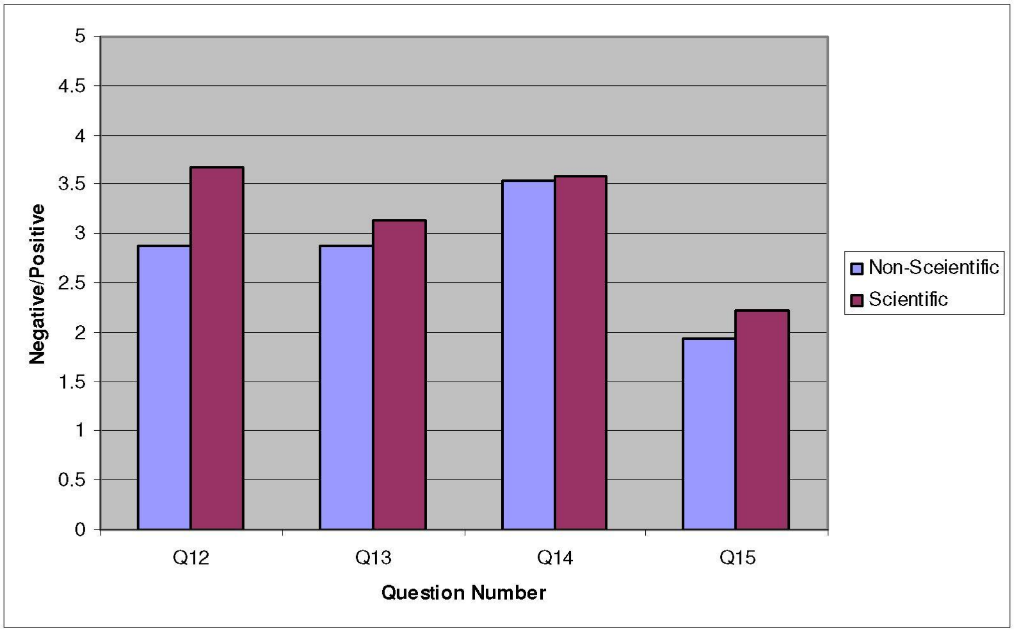

Figure 09. Manufacturing response comparisons

Figure 9 illustrates the differences in responses between people of scientific and non-scientific backgrounds. Though minimal, the responses clearly show some correlation related to the background of the participants. It is hardly possible to say that there is a definite causal relationship, but the non-scientific people have a more pessimistic outlook upon nanotechnology manufacturing applications according to our results.

Among scientists, a debate over the future of nanotechnology exists. There are those who believe that many wonderful things will come from the future of nanotechnology, and those who feel that it may prove a fruitless venture. Eric Drexler and his supporters believe that the future of this technology is bright. They imagine future benefits from creations such as the "bread box assembler" (Newton 2002), which a box that will be able to produce any item so long as it's programmed into the nanobots inside. They also imagine a nearly waste free manufacturing environment, keeping pollution and other such negative effects at a minimum.

Despite these concerns and doubts, there have been many short term gains from the use of nanotechnology. These uses have not had a negative impact upon the environment, nor have they created a debate among the common person. Our research has shown that the common person is unaware that nanotechnological applications are used in industry today (and online surveys also add hard data from UK study). With this understanding, the scientific community has begun its response by having seminars and major studies conducted to spread public awareness (Toumey 2004).

Summary and Recommendations

The problem people have is with self-replication. They fear grey goo when it is suggested to them. In the professional studies, grey/green goo is not directly, nor indirectly mentioned in any way by the participants (Nanotechnology: Views of the General Public 2004). There is a strong concern with general new technology fear, not with grey goo. When the idea is introduced to people, specifically as a question in a survey/poll (i.e. web-based polls), people get nervous and those particularly not confident in the technical aspects become afraid. Our survey results supported this theory, showing that people of a non-scientific background were less comfortable with and knowledgeable about nanotechnology. The NSF document *Societal Implications of Nanoscience and*

Nanotechnology from 2001 is composed of several articles from the scientific community. It expresses concern for the grey goo theory from the scientific community. The person-on-the-street questions all have a positive outlook upon nanotechnology, until grey goo is mentioned directly. The real concern with grey goo is in the scientific (Eric Drexler) and political communities (Pat Mooney).

This demonstrates a need for the scientific community to introduce the idea of grey goo into common knowledge in order for it to be taken into consideration. In December 2004, the NNI demonstrated the need to educate the general population on nanotechnology to the President of the United States. Subsequently, funding for nanotechnology related research has increased, as well as a call for papers on the societal implications on nanotechnology. We suggest that future projects at WPI partake in this call, for it is an important issue to resolve.

Appendices

Appendix A: Survey Questions

Age _____ Sex ____ Profession ____________

Please rate each of the following statements on the scale of 0-5.

0 - I do not know enough to answer this question;

1 - Strongly Disagree; 2 - Disagree; 3 - Neutral; 4 - Agree; 5 - Strongly Agree

1. I would rate myself as being knowledgeable on the topic of nanotechnology.
2. I would not be opposed to the use of nanotechnology in a way that directly affects me.
3. The prospect of nanotechnology being more widespread across society does not bother me.
4. I am aware that many common objects already utilize and contain passive forms of nano-materials (such as stain-resistant clothing and sports equipment).
5. I would not be opposed to using products that contain nano-materials in a passive form.

5a. I would be comfortable using products that contain nano-materials in an active-form.

6. I would not be opposed to the military using nanotechnology for surveillance, armor, and other uses.
7. Many cosmetic companies currently utilize nanotech in their products, and this does not deter me from using them.
8. I would not be opposed to the use of nanobots assisting with the necessary bodily functions of myself or a loved one.
9. I consider the development of nanotechnology for medical purposes as a good alternative to stem-cell research.
10. I would feel comfortable allowing nanobots to regulate the administration/release of medication to my body.
11. I feel positively about the possibility of nanotechnology being used to help repair nerve damage in paralyzed persons.
12. I would feel comfortable working in an environment where nanotechnology is developed and manufactured.
13. I do not feel that the field of nanotechnology would pose a greater threat tot the environment than current manufacturing techniques.
14. I am aware that nanotechnology is already being used in the manufacturing of computer and electronic devices.
15. I am comfortable with the prospect of self-replicating nanobots.

Appendix B: Raw Survey Data

Table 01. Survey Data part A

Respondent	Background	Q1	Q2	Q3	Q4	Q5	Q5a
1	non-scientific	4	3	4	4	4	2
2	non-scientific	4	2	3	5	5	4
3	non-scientific	1	0	0	2	0	0
4	non-scientific	0	3	2	1	3	3
5	non-scientific	3	4	4	4	4	3
6	non-scientific	1	3	4	5	3	3
7	non-scientific	3	3	3	4	3	0
8	non-scientific	1	5	5	5	5	5
9	non-scientific	1	0	0	1	0	0
10	non-scientific	1	3	4	0	4	4
11	non-scientific	4	2	4	4	4	3
12	non-scientific	1	4	5	2	5	3
13	non-scientific	2	4	2	2	5	5
14	non-scientific	3	4	4	4	4	4
15	non-scientific	4	1	5	5	4	4
16	non-scientific	3	4	4	4	4	3
17	non-scientific	4	2	2	4	2	1
18	scientific	1	2	2	1	2	2
19	scientific	1	3	3	1	4	4
20	scientific	5	4	4	5	4	4
21	scientific	4	2	2	4	4	2
22	scientific	3	4	4	4	5	0
23	scientific	2	3	1	4	5	3
24	scientific	2	5	1	2	5	4
25	scientific	3	4	5	2	5	3

Table 02. Survey Data part B

Respondent	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
1	4	3	4	3	4	4	4	4	4	2
2	5	0	1	4	1	5	5	4	5	1
3	0	0	1	0	1	0	0	0	4	1
4	2	4	5	2	3	5	1	0	0	3
5	4	3	4	3	3	4	4	3	5	2
6	3	3	5	5	5	4	3	3	3	1
7	3	3	4	4	3	4	0	0	5	0
8	5	5	5	5	5	5	5	5	5	5
9	5	0	4	0	4	5	0	0	0	0
10	0	0	0	3	0	4	3	4	4	0
11	4	4	4	3	3	4	3	4	3	3
12	3	4	3	4	0	3	0	4	3	2
13	2	5	1	2	2	5	4	3	4	1
14	5	3	4	3	3	5	4	4	2	3
15	0	0	3	0	3	4	4	4	5	3
16	5	4	2	2	1	1	5	4	4	4
17	1	2	3	3	2	4	4	3	4	2
18	3	0	1	2	1	3	2	0	1	1
19	5	3	5	5	5	5	5	5	2	1
20	3	4	3	4	3	4	4	4	5	2
21	3	2	1	4	2	3	3	4	4	1
22	3	5	4	0	0	4	2	4	5	2
23	4	5	2	3	4	5	5	5	5	3
24	3	4	4	2	4	4	4	3	4	2
25	4	1	3	4	3	5	4	5	5	3

Table 03. Survey Data part C

Respondent	Profession	Q1	Q2	Q3	Q4	Q5	Q5a
26	scientific	0	4	5	0	5	5
27	scientific	4	4	3	5	5	4
28	scientific	2	0	3	2	3	3
29	scientific	2	4	2	5	5	4
30	scientific	1	3	3	1	3	3
31	scientific	4	3	3	4	5	3
32	scientific	3	5	4	5	3	3
33	scientific	4	4	3	5	5	3
34	scientific	2	4	3	3	4	4
35	scientific	1	3	4	2	4	3
36	scientific	3	3	2	4	4	3
37	scientific	1	3	4	4	4	3
38	scientific	2	4	3	3	4	4
39	scientific	2	5	2	3	5	4
40	scientific	3	4	5	2	5	3
41	scientific	3	1	2	5	5	2
42	scientific	4	5	5	5	5	4
43	scientific	4	4	4	4	5	3
44	scientific	4	5	5	4	5	5
45	scientific	4	4	4	5	5	4
46	scientific	1	3	3	2	4	4
47	scientific	3	4	2	4	5	2
48	scientific	3	3	3	0	3	4
49	scientific	4	5	5	5	5	4
50	scientific	2	3	5	4	5	5
51	scientific	3	4	5	5	5	4
52	scientific	1	2	3	2	4	3
53	scientific	1	3	3	2	5	2

Table 04. Survey Data part D

Respondent	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
26	5	5	5	4	5	5	5	5	0	2
27	5	3	1	5	3	5	5	3	5	3
28	3	3	3	0	0	0	3	0	1	0
29	4	5	5	4	4	4	5	4	4	2
30	3	4	3	3	3	4	3	3	3	3
31	3	3	4	2	3	5	5	5	4	3
32	4	3	4	5	5	4	4	3	3	2
33	3	0	4	3	3	3	3	3	4	2
34	4	2	4	4	3	5	3	3	4	2
35	3	0	2	3	2	4	3	0	4	2
36	2	3	4	3	1	4	4	4	3	4
37	5	3	4	4	4	4	4	3	2	3
38	4	2	2	2	3	5	3	3	4	2
39	4	4	4	4	0	4	0	4	2	0
40	2	4	3	3	4	4	3	0	2	2
41	5	0	1	2	1	2	3	1	5	3
42	5	5	3	2	4	5	5	5	5	3
43	5	3	3	3	4	4	5	3	5	2
44	5	3	5	5	5	5	3	5	5	4
45	5	0	4	3	3	4	4	4	4	3
46	4	4	2	3	4	5	4	3	1	2
47	5	2	1	0	2	5	2	0	5	1
48	1	2	5	3	4	4	4	4	2	1
49	5	5	4	4	4	4	5	4	5	4
50	3	3	4	5	5	5	5	5	5	5
51	4	5	3	4	3	5	4	0	5	2
52	3	0	4	3	3	4	3	3	5	1
53	1	3	1	0	4	4	3	3	1	2

Appendix C: Products Currently Using Nanotechnology

- Eddie Bauer Nano-Care Khakis along with Gap khakis and Levi's Dockers use molecular structures created to form a barrier between fibers of cotton and stain-causing materials
- The Kodak Easyshare LS633 is a digital camera that uses a low-powered nanostructured organic light-emitting diode (LED) display.
- The 2004 Chevrolet Impala and some Hummer models save more fuel due to the lightweight nanocomposite materials used on body side moldings
- EcoTru is a hospital-grade cleanser that uses "nanoemulsions" to kill bacteria without using as much chemicals as non-nano cleansers do
- The U.S. Navy uses nanoscale coatings to prevent barnacles and mollusks from adhering to the hulls and propulsion shafts of their battleships
- Many cosmetics companies like Estee Lauder are using nanosized iron oxide as a pigment in lipstick and hair dyes. Also titanium dioxide and zinc oxide nanoparticles are used in sunscreens due to their ability to reflect ultraviolet light and remain transparent to visible light.
- L'Oreal blends liquid nanoparticles into face creams to help moisturizer to penetrate deep into the skin
- Intel's Pentium 4 and other chips currently use circuit elements that are smaller than 100 nanometers
- IBM designed a nanocomponent known as GMR (Giant Magnetoresistor) is used to bolster performance of hard drives
- General Motors has used nanofillers in their SUVs and vans for years
- Companies like Cabot Corp. manufacture nanoparticles to provide the high-gloss coating on certain types of paper
- GE sells plastic for use in automobiles that include nanofillers which will allow paint to bind more readily to it
- "BASF's annual sales of aqueous polymer dispersion products amount to around $1.65 billion. All of them contain polymer particles ranging from ten to several hundred nanometers in size. Polymer dispersions are found in exterior paints, coatings and adhesives, or are used in the finishing of paper, textiles and leather. Nanotechnology also has applications in the food sector. Many vitamins and their precursors, such as carotinoids, are insoluble in water. However, when skillfully produced and formulated as nanoparticles, these substances can easily be mixed with cold water, and their bioavailability in the human body also increases. Many lemonades and fruit juices contain these specially formulated additives, which often also provide an attractive color."
- Using aluminum nanoparticles, Argonide has created rocket propellants that burn at double the rate. They also produce copper nanoparticles that are incorporated into automotive lubricant to reduce engine wear.
- Nanodyne makes a tungsten-carbide-cobalt composite powder (grain size less than 15nm) that is used to make a sintered alloy as hard as diamond, which is in turn used to make cutting tools, drill bits, armor plate, and jet engine parts.

- Nanocor is one company producing nanoclays and nanocomposites, for a variety of uses, including flame retardants, barrier film (as in juice containers), and bottle barrier
- Wilson Double Core tennis balls have a nanocomposite coating that keeps it bouncing twice as long as an old-style ball. Made by InMat LLC, this nanocomposite is a mix of butyl rubber, intermingled with nanoclay particles, giving the ball substantially longer shelf life.
- Nanoledge makes carbon nanotubes for commercial uses, of which one mundane (marketing tactic) use is in a tennis racket, made by Babolat. The yoke of the racket bends less during ball impact, improving the player's performance.
- Applied Nanotech recently demonstrated a 14" monochrome display based on electron emission from carbon nanotubes.
- Elixir NanoWeb guitar strings utilize a nanoparticle webbing that houses steel strings to allow for better tone and a longer lasting set of strings.

Appendix D: Fears Regarding the Development of Nanotechnology

- The prospect of “grey goo”
- Environmental dangers
  - Water, air, and earth pollution that cannot be cleaned
  - Health risks to animals, could result in destruction of food chains
- Health risks to humans
  - What if a nanobot went haywire inside someone’s body and hurts or kills them instead of helping them?
  - People could purposely use nanomachines as undetectable assassins
  - Affects from breathing in nanoparticles could harm our lungs and breathing apparatus
  - The possibility of a nano swarm taking control of people a la *Prey*
- Terrorists could use developments to purposely harm people
- “Designer” drugs could be developed for purposes other than healing
  - Malicious drugs could be used to hurt people
  - New addictive “pleasure” drugs could be developed

Appendix E: Financial Data for the Field of Nanotechnology

Table 05. Funds invested in nanotechnology-related areas for various organizations

Fiscal year (all in million $)	*2000* Actual	*2001* Enact/Actual	*2002* Enact/Actual	*2003* Enact/Actual	*2004* Req./ Enact	*2005* Req
National Science Foundation	97	150 /150	199 /204	221 /221	249 /254	305
Department of Defense	70	110 /125	180 /224	243 /322	222 /315	276
Department of Energy	58	93 /88	91.1 /89	133 /134	197 /203	211
National Institutes of Health	32	39 /39.6	40.8 /59	65 /78	70 /80	89
NASA	5	20 /22	35 /35	33 /36	31 /37	35
NIST	8	10 /33.4	37.6 /77	66 /64	62 /63	53
EPA	-	/5.8	5 /6	5 /5	5 /5	5
Homeland Security (TSA)	-		2 /2	2 /1	2 /1	1
Department of Agriculture	-	/1.5	1.5 /0	1 /1	10 /1	5
Department of Justice	-	/1.4	1.4 /1	1.4 /1	1.4 /1	1
TOTAL	270	422 /465	600 /697	770 /862	849 /961	982

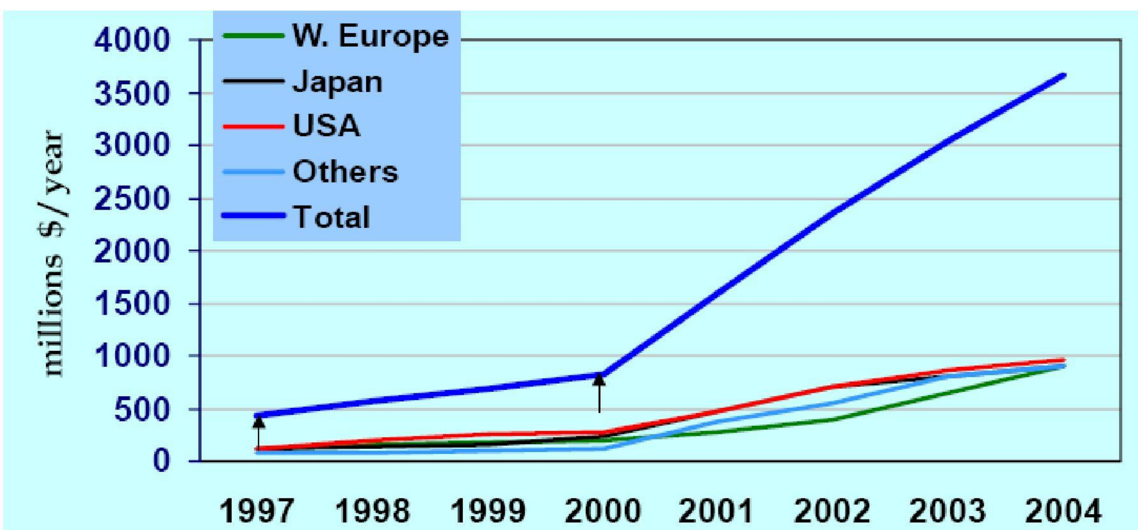

Figure 10. International financial spendings

Appendix F: Patent Trends for Nanotechnology

Table 06. Full text search for nanotechnology related terms

(a) Nano terms	Full text search		
	1976-2002	1976 - 2003	2003
self assembly	1238	1571	333
self assembled	1058	1374	316
self assembling	626	762	136
self-assembly	1111	1409	298
self-assembled	999	1297	298
self-assembling	581	705	124
atomic force microscopic	1710	2034	324
atomic force microscopic	34	40	6
atomic force microscopy	1197	1468	271
atomic-force-microscope	2	3	1
atomic-force-microscopy	2	2	0
scanning tunneling microscope	967	1048	81
scanning tunneling microscopic	17	19	2
scanning tunneling microscopy	690	766	76
scanning-tunneling-microscope	24	25	1
scanning-tunneling-microscopy	1	1	0
atomistic simulation	5	5	0
biomotor	4	6	2
molecular device	104	135	31
molecular electronics	199	229	30
molecular modeling	1336	1595	259
molecular motor	59	77	18
molecular sensor	17	22	5
molecular simulation	33	37	4
quantum computing	25	47	22
quantum dot*	352	475	123
quantum effect*	467	521	54
nano*	55366	62743	7377
Total	**68224**	**80081**	**11857**
Unique Total	61409	70039	8630

Table 07. Title and title claims search for nanotechnology-related terms

(b) Nano terms	Title search 1976-2002	Title search 1976 - 2003	Title search 2003	"Title - claims" search 1976-2002	"Title - claims" search 1976 - 2003	"Title - claims" search 2003
selfassembl*	0	0	0	3	3	0
self assembly	23	31	8	134	163	29
self assembled	53	68	15	181	222	41
self assembling	40	44	4	359	430	71
self-assembly	20	26	6	86	97	11
self-assembled	49	62	13	106	128	22
self-assembling	36	40	4	81	92	11
atomic force microscopic	0	0	0	1	1	0
atomic force microscopic	0	0	0	1	1	0
atomic force microscopy	14	17	3	69	85	16
atomic-force-microscope	0	0	0	0	0	0
atomic-force-microscopy	0	0	0	0	0	0
scanning tunneling microscope	65	67	2	183	198	15
scanning tunneling microscopic	0	0	0	0	0	0
scanning tunneling microscopy	10	10	0	47	48	1
scanning-tunneling-microscope	0	0	0	0	0	0
scanning-tunneling-microscopy	0	0	0	1	1	0
atomistic simulation	0	0	0	0	0	0
biomotor	0	0	0	0	1	1
molecular device	0	0	0	8	10	2
molecular electronics	0	0	0	0	0	0
molecular modeling	3	3	0	24	31	7
molecular motor	0	0	0	2	2	0
molecular sensor	0	0	0	5	6	1
molecular simulation	1	1	0	2	2	0
quantum computing	4	9	5	7	19	12
quantum dot*	36	46	10	108	150	42
quantum effect*	12	12	0	51	56	5
nano*	954	1254	300	8840	10364	1524
Total	**1356**	**1728**	**372**	**10299**	**12110**	**1811**
Unique Total	**1196**	**1538**	**342**	**9562**	**11206**	**1644**

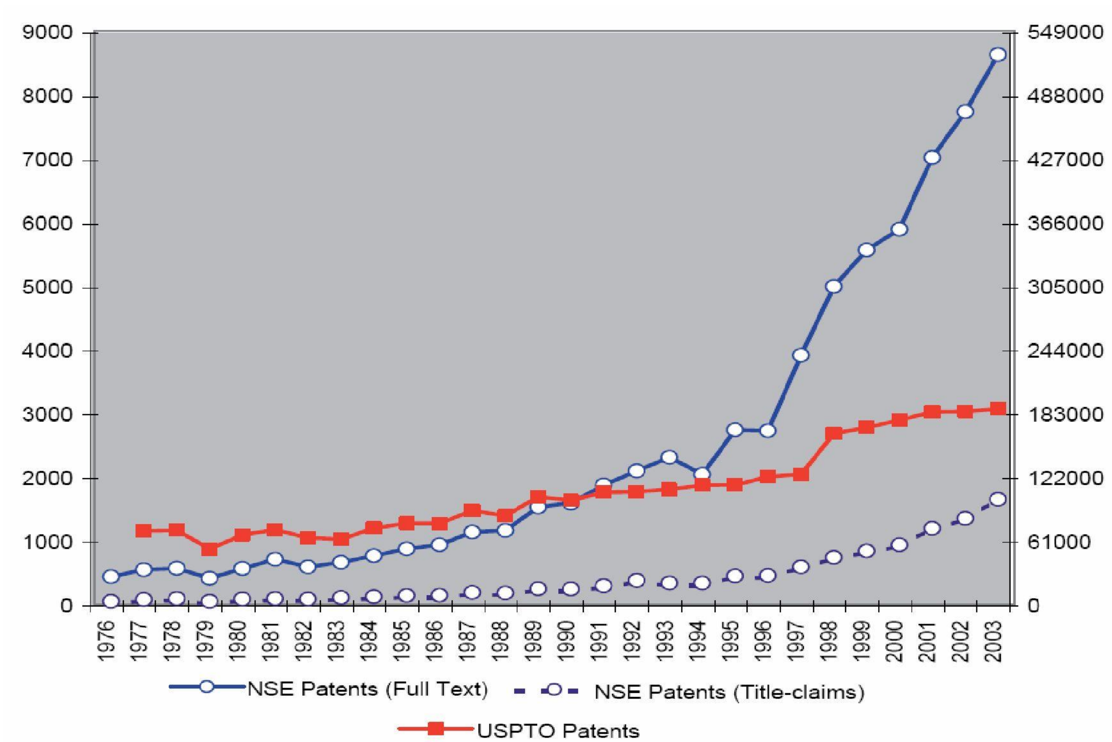

Figure 11. Comparison of patent search results

Appendix G: Works Cited

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