Social Acceptance of Fail-Safe Nanotechnology

AN INTERACTIVE QUALIFYING PROJECT

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Degree of Bachelor of Science

by

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Abstract

Nanotechnology has vast potential to benefit humanity, though some people think it is too dangerous to pursue further. In response, possible fail-safe mechanisms are proposed that could prevent potential harm. By educating individuals through a Wikipedia article and surveying 348 people, it was determined that social acceptance of nanotechnology increases as the level of self-proclaimed knowledge of nanotechnology increases, confirming the hypothesis that a greater knowledge about nanotechnology will result in its greater acceptance.

Executive Summary

Almost every new technology has initially met the world with opposition, because of the fears that instinctively arise in humans when a lack of knowledge is present. This occurred with the development of genetically modified foods, vaccinations, and nuclear energy[1]. This can severely inhibit the development of any new technology, such as nanotechnology. The hypothesis of this IQP project is that if the public is informed of possible fail-safe methods regarding nanotechnology, then the general social acceptance will be positive, which may allow for further development of the technology.

In order to prove this, the IQP team first proposed possible fail-safe mechanisms that can effectively eliminate possible sources of harm to a user. Through an article on Wikipedia, the public was educated about nanotechnology and the fail-safe methods. The users were then asked to take our online survey and tell the team what their opinions on nanotechnology and the fail-safes are. Wikipedia users were not the only population to be surveyed, as the team also obtained the opinions of the WPI faculty, WPI students, and also an online gaming website, which provided many different backgrounds and levels of education.

The survey was constructed to have twenty questions, where question one is important because it asks the user's self-proclaimed level of knowledge, and question two reinforces their level of knowledge. Questions three through five have to do with our proposed mechanical fail-safes, questions six through ten have to do with DNA/amino acids fail-safes, questions eleven through fifteen have to do with antibiotic and protein

[1] Sklyar, A., J. Smith, C. Stedman II. *Social Acceptance of Technologies*. IQP 2006. Worcester Polytechnic Institute

based fail-safes, and finally questions sixteen through twenty have to do with programming fail-safes for nanotechnology.

The questions were normalized using a scale of -1 to 1, which represents the chosen level of acceptance. A rating of -1 is interpreted that the user is very uncomfortable with the question, and a rating of 1 is interpreted that the user is very accepting of the question. If a user's rating is a zero that means that they are indifferent or undecided on the question being asked. In the case of question one of the survey, a -1 means that the user claims to have no knowledge on nanotechnology, a zero means average knowledge, and a 1 means the user claims to be extremely knowledgeable on nanotechnology.

The initial goal of having a target population greater than a minimum of thirty people was met. The group surveyed 252 WPI students, 30 WPI professors, 52 people in a public forum, and 14 Wikipedia users. The results from the survey met a 95% confidence interval with +5% sampling error, both in WPI students and in WPI professors[2]. This sample size is a good representation of the WPI academic population. Our data show an overall acceptance of 0.41 with students, 0.27 with professors, 0.33 with forum users, and 0.41 with Wikipedia users. The linear best fit line of all the data displayed an upward trend across the knowledge range, beginning with a value of 0.33 and rising to 0.60. While the team only surveyed 348 users from our selected target populations, it was determined that social acceptance of nanotechnology is dependent on the level of self-proclaimed knowledge of nanotechnology, confirming the hypothesis of this IQP project.

[2] Salant, P., and D. Dillman. *How to Conduct Your Own Survey.* New York: John Wiley & Sons, Inc, 1994.

1. Introduction

1.1 NANOTECHNOLOGY: DEVELOPMENT AT THE ATOMIC SCALE

Nanotechnology is defined by NASA as the creation of functional materials, devices and systems through control of matter on the nanometer length scale (1–100 nm), and exploitation of novel phenomena and properties (physical, chemical, biological, mechanical, electrical...) at that length scale[3]. To give some perspective, one nanometer is roughly the length of a glucose sugar molecule, and one-hundred nanometers is the about the width of the average virus. This is demonstrated in Figure 1 below. Nanotechnology is essentially the creation of products in which the individuals pieces used are single atoms or molecules.

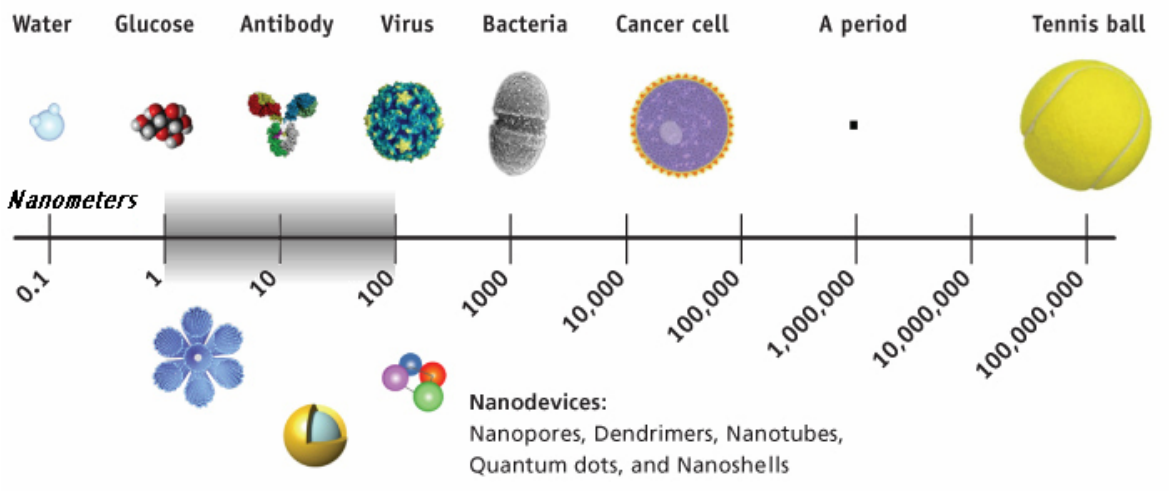

Figure 1 - Nanometer Length Scale[4]

[3] Scheu, M., V. Veefkind, Y. Verbandt, E. Molina Galan, R. Absalom, W. Forster, Mapping nanotechnology patents: The EPO approach, World Patent InformationVolume 28, Issue 3, , September 2006, Pages 204-211. <http://www.sciencedirect.com/science/article/B6V5D-4K7FJ55-1/2/73309b4ceb263b1b9804bd4ba6f63138>

[4] "FDA Readies for More 'Nanoscale' Challenges." U.S. Food and Drug Association. 25 July 2007. U. S. 08 Dec. 2008. < http://www.fda.gov/consumer/updates/nanotech072507.html>

The conception of nanotechnology first appeared in a talk by physicist Richard Feynman titled “There’s Plenty of Room at the Bottom” during an annual American Physical Society meeting at the California Institute of Technology on December 12, 1959. The term “nanotechnology” was not coined, however, until fifteen years later in a paper titled "On the Basic Concept of *Nano-Technology*," by Norio Taniguchi, a Tokyo Science University Professor[5]. It was another fifteen years until nanotechnology received wide-spread interest when IBM used a scanning tunneling microscope to depict the company’s corporate logo on a piece of nickel with 35 xenon atoms in 1989[6]. Currently, nanotechnology is being used in a wide range of consumer products such as personal computers, automobiles, and clothing. For example, the new Intel Atom processor uses 47 million complementary metal-oxide-semiconductors that are just 45nm in size, in order to create a high speed processor smaller than a penny[7]. This processor can be seen in Figure 2. Thus far modern applications have only implemented fixed nano-structures. The future for nanotechnology will most likely result in automated nanobots, biological nano-machines, and computer processing technology.

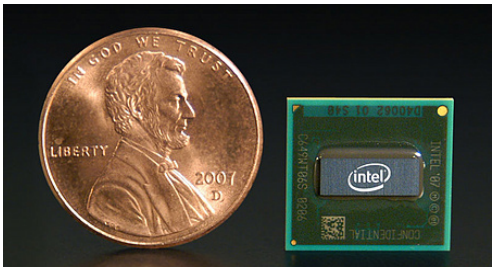

Figure 2 – Intel Atom Processor as compared to penny.[8]

[5] Taniguchi, N. "On the Basic Concept of 'Nano-Technology'," *Proc. Intl. Conf. Prod.* London, Part II, British Society of Precision Engineering, 1974.
[6] Pollack, A. “Atom by Atom, Scientists Build 'Invisible' Machines of the Future.” New York Time 26 Nov. 1991.
[7] “Introducing Intel’s Smallest Processor.” Intel Atom Processor. Intel. 10 Feb, 2009. <http://www.intel.com/technology/atom/>
[8] Mokey, N. “Top Ten Tech Innovations of 2008.” Digital Trends. 2008. Feed Burner. 20 Feb. 2009. < http://news.digitaltrends.com/feature/95-page-2/top-10-tech-innovations-of-2008>

During our initial research, a few particular fields within nanotechnology stood out as the most prominent regions to encourage safe development. These regions span a wide range of science, but can be categorized into the four basic aspects of: mechanical, DNA/amino acids, antibiotics/proteins, and programming.

DNA molecules and amino acids are currently being studied for use in nanotechnology. Both are practical routes because they are very predicable and easily constructed molecules, and are very manageable to replicate any number of times. Synthetic amino acids are created and connected to form bis-peptides. These differ from peptides in the human body because they have two bonds between the acids instead of one, which makes them very easy to distinguish from human peptides. These bis-peptides can be used as indicators that would fluoresce when exposed to certain molecules, or as mechanical systems such as actuators or valves.[9] Research in DNA nanotechnology has proven that DNA molecules can be used to create very strong and rigid structures due to their double helix configuration. In an article titled *Nanotechnology and the Double Helix* the author, Nadrian C. Seeman[10], describes how DNA molecules can be used to create complex lattice structures, as well as nano-sized motors given the appropriate environment. DNA appears to be a very promising direction because so many processes regarding replicating, cutting, splicing, and connecting DNA molecules already occur everyday within the human body, and are very efficient.

Antibiotics and synthetic proteins can also be valuable materials in the development of nanotechnology. Research in synthetic proteins is very similar to that in

[9] Schafmeister, C. E. "Molecular Lego" Scientific American Reports. Sep. 2007: 22-29.
[10] Seeman, N. C. "Nanotechnology and the Double Helix." Scientific American Reports. Sep. 2007: 30-39.

amino acids, and offers nearly the same benefits. Synthetics proteins are very similar to the peptides described earlier, but are built with molecules other than amino acids. This gives them a wider range of uses, but may make them more difficult to produce because of the lack of preexisting biological processes associated with them.[11] Antibiotics would be used in correlation with another technology, cellular engineering. Bacteria cells are currently being tested as carriers for drug delivery in the body. These bacteria are programmed with manufactured plasmid DNA rings, a technology on the nanometer scale. Specific antibiotics can be developed for these programmed bacteria, in the event that they need to be stopped or eliminated.[12]

Programming much like modern computer programming might become a very useful tool in nanotechnology. This will be possible because computers could be built at the nano-scale. In an article titled "*Bringing DNA Computers to Life"* authors Ehud Shapiro and Yaakov Benenson[13] describe their research in computing machines made of DNA molecules. Shapiro and Benenson wrote their own DNA sequence (similar to software), and combined it with the appropriate enzymes (hardware), and then used the DNA to find the solution to a simple problem. An artist's rendition of this process may be seen in Figure 3. It became evident that the rate at which biological reactions occur is too slow for a DNA computer to be able to match the speed of a modern electronic machine. However, there is a clear advantage to the DNA computer; since it is made of the same molecules in one's body, it would be able to directly communicate with cellular

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[11] "Yale Chemists Show that Nature Could have Used Different Protein Building Blocks." Yale University Office of Public Affairs. 5 Feb. 2007. Yale University. 29 Oct. 2008. <http://opa.yale.edu/news/article.aspx?status=301&id=2078>

[12] Potera, C. "Bioengineering Bacteria for Drug Delivery." Genetic Engineering & Biotechnology News. 15 Feb. 2007. 14. genengnews.com. 27 Oct. 2008. < http://www.oselinc.com/files/GEN.pdf>

[13] Shapiro, E., Y. Benenson. "Bringing DNA Computers to Life." Scientific American Reports. Sep. 2007: 40-47.

processes. This means detecting and fighting disease in the human body could be a very likely and plausible use for this upcoming technology.

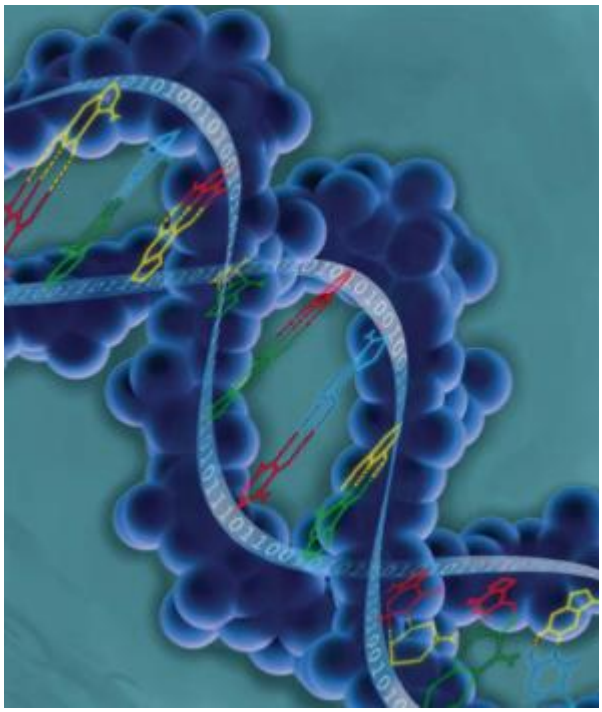

Figure 3 - DNA stores data naturally, making it ideal raw material for building computers.[13]

1.2 PREVIOUS RESEARCH

As the IQP team began this project, it was realized that it was necessary to look at previous research conducted by others to help us develop our desired goals for the project. The team looked into not only research done by outside sources, but also previous nanotechnology IQP projects. The combination of these two areas of research provided a solid base in order to propose a hypothesis and goals for this 2008-2009 nanotechnology IQP project.

A 2004 article, called *Nanotechnology: Views of the General Public*[14], helped the team to discover how people feel about nanotechnology, but also why people feel the way they do. This article examines thoroughly how people make decisions about new technologies, and what aspects affect these decisions. This may be due to a wide variety of reasons, a few of them being whether it is a consumer or a non-consumer product, the speed of development of the technology, and also the amount of knowledge on the topic. The article then turns its focus to nanotechnology specifically, and how people's decisions are made about this particular technology. Interestingly, only 29% of people are even aware of what nanotechnology is based on results from their surveyed population. Even for those who have heard of nanotechnology, the extent of their knowledge was very low. Only 19% of the population was able to define nanotechnology. As the article looked into how people felt about nanotechnology, it was found that without concrete examples of how nanotechnology could be used, it was very difficult for people to know how they feel about it. The public was found to have negative views of nanotechnology due mainly due to these areas: ethical issues, financial issues, social and political issues, environmental issues, and health and safety risks. For the purposes of this IQP project, the team focused on proposing a method to eliminate the health and safety issues that caused fears in the public.

The goals of this IQP project were formed not only by gaining an understanding of how the public views nanotechnology, but also with a good understanding of past IQP projects and their conclusions. The first Nanotechnology IQP titled "*Will Prey Consume Nanotechnology?"* simply focused on the idea that the development of the new

[14] "Nanotechnology." Views of the General Public. 2004. BMRB Social Research. 10 Feb. 2009. < http://www.nanotec.org.uk/Market%20Research.pdf>

technology might be inhibited by public fears such as the Grey Goo theory. Surprisingly WPI students seemed to be fairly accepting of nanotechnology, and those who had very little knowledge, if any, about nanotechnology were the most accepting[15]. The second IQP entitled "*Social Acceptance of Technologies"* compared past technologies that faced opposition, vaccinations, genetically modified foods, and nuclear energy, with nanotechnology. Their conclusion was that the most important factor in acceptance of any technology was the personal benefit vs. the risk factor ratio[1]. The third nanotechnology IQP entitled "*Social Acceptance of Nanomedicine"* researched deeply into the multiple parameters of the human decision-making process. They used nanotechnology in medicine as the basis for their social research, and found that other factors such as price or efficiency could have just as much influence as any fears regarding a new technology[16]. The fourth IQP called "*The Effect of an Educational Video on the Acceptance of Nanotechnology"* surveyed individuals before and after they were educated about present nanotechnology and then compared those acceptance levels. To inform the survey groups, a nonbiased, informative, short video was shown between surveys. Their results revealed that the acceptance of nanotechnology was less after the video was watched[17]. All four of these projects were taken into consideration when developing the 2008-2009 Nanotechnology IQP and had a large influence on the objective that was chosen.

[15] Allwood, T., K. Psiakis, T. Regan. *Will Prey Consume Nanotechnology?* IQP 2005. Worcester Polytechnic Institute.
[16] Arenas, N., K. M. Ryan. Subashi, M. *Social Acceptance of Nanomedicine*. IQP 2007. Worcester Polytechnic Institute
[17] Beavers, D. A., C. Goodrich, B. Kaufman. *The Effect of an Educational Video on the Acceptance of Nanotechnology*. IQP 2008. Worcester Polytechnic Institute

1.3 MOTIVATIONS FOR IQP TOPIC

For this IQP project, the team decided to take a more active approach than in previous years. The social acceptance of nanotechnology has repeatedly been shown to be unfavorable.[18] In order to raise this acceptance our team wanted to inform the public that fail-safe principles which are currently standard practice in engineering of other technologies could be applied to nanotechnology. Our team hoped that through the IQP project, they could increase the common awareness and acceptance of nanotechnology, and resultantly increase the development and implementation of nanotechnology in the common world.

The information within the IQP tends to focus on areas of biomedical research, mechanical systems, and electrical programming. This is because these are fields that the team members had previous experience with when entering the IQP project. The methods used for the education and surveying of the public were chosen to be entirely electronic and online. This is because the team believed that this form of communication would be the most productive and successful considering the knowledge of the team members and the four populations involved in the project. The overall motive for the direction of the 2008-2009 Nanotechnology IQP project was to help further the development of nanotechnology for practical commercial applications.

1.4 IQP HYPOTHESIS AND GOALS

This IQP was developed and executed with the intent to accomplish three main goals and to prove our hypothesis. This hypothesis of this IQP project is that if the public

[18] Weiss, R. "Stricter Nanotechnology Laws are Urged." The Washington Post. 11 Jan. 2006. The Washington Post Company. 2 Oct. 2008. < http://www.washingtonpost.com/wp-dyn/content/article/2006/01/10/AR2006011001520.html>

is informed of possible fail-safe methods regarding nanotechnology, then the general social acceptance will be positive, which might allow for further development of the technology. The first goal of this IQP project was to study and report on the areas of present research that have nanotechnology fail-safe capabilities, and could be used to control or inhibit various nanotechnologies to prevent any unwanted, unexpected, or harmful outcomes.

The second goal was to inform the public on the fail-safe methods and devices regarding nanotechnology that are achievable according to current research. In order to realize this goal a Wikipedia article was created titled Nanotechnology Fail-Safes. This is an online encyclopedia article available to everyone that describes what our research has produced for fail-safes in nanotechnology.

And finally, the primary goal within this IQP was to conduct a survey to determine if the level of self-proclaimed knowledge would affect acceptance and which fail-safe methods would be most accepted. This survey was designed to explore the level of risk that the public associates with nanotechnology, and to determine which fail-safes would make people the most accepting of nanotechnology. In addition, the survey determined whether each fail-safe would make the public positively favor the development of nanotechnology.

1.5 NANOTECHNOLOGY FAIL-SAFES

Our Wikipedia article consisted of seven sections: introduction, ferrous nanoparticles, amino acids, DNA, programming, cellular engineering, and IQP project. In the introduction the team introduces the topic of the article, and describes what is meant by a fail-safe for nanotechnology. The ferrous nanoparticles section looks into how

nanobots or other nano-structures could be built using ferrous materials in their structure and circuits, and finally how a magnetic field could be use to hinder the actions of these structures. The amino acids section describes how nanostructures can be built with synthetic proteins, which differ from naturally occurring proteins in the human body, meaning that they can be easily isolated and targeted for destruction. The DNA section of the article discusses how nanostructures can be built using DNA molecules and in the event of failure, synthetic proteins similar to the ones that breakdown DNA during cellular reproduction can be used to degrade the structures. A two-layer approach is described in the programming section. This includes pre-programmed circuits that will shut down a nanobot should it get out of control, and also the ability for the bots to be over-ridden and "remotely controlled" by a specialist effectively erasing causes of harm to the user. In the cellular engineering section, the team notes that bacteria can be used to deliver drugs to specific locations in the human body. If the bacteria cause any harm to the user, antibiotics can be used to eliminate risk. Finally, the IQP section introduces the institution this project is from, WPI, and kindly asks users to complete our survey which is linked on the page. For further information see Appendix B.

2. Methodology

The Methodology portion of this report will describe how the survey was developed, from deciding on a target population to how the data will be interpreted. The individual questions will not be addressed in detail; the questions can be found in Appendix C.

2.1 TARGET POPULATION

Several main sources of survey data were used to broaden the range of individuals available for participation. To ensure that we reached a more eclectic population, we not only surveyed WPI students and professors, but also members of the online community via Wikipedia and a broad-based gaming forum. As in previous IQP projects, we used *How to Conduct Your Own Survey* to assist us in setting our goal for the number of survey results from each of our four groups[2]. As it is difficult to determine the population of the forum as well as Wikipedia, our target was the generally accepted thirty result minimum required for statistical significance. For the WPI professors and students we originally aimed for the thirty result minimum, but later decided on approximately eight percent of each population. This resulted in 252 WPI Students and 30 WPI Professors. We also received 52 responses from a public forum, and 14 from Wikipedia users. However, the data collected were enough to ensure that we cut down our sampling error to a sufficiently low level for acceptable error.

2.2 DATA COLLECTION

All of the surveys were conducted online through the use of a webpage created by the team. The primary reason for creating the survey online was that the data would be electronic and easier to collect in large quantities. Prizes were also offered by the team as a form of incentive to improve user participation levels. The prizes came in several forms: gift cards, WPI merchandise, and gaming points.

To promote the survey on the WPI campus, several methods were used by the team. Members of the team table-sat in the Campus Center, requesting that students take the survey, as well as handed out business cards containing the survey link to those who were busy when approached. This business card may be seen in Figure 4. The WPI professors were visited in their offices, and were either asked to take the survey at that time, or given a card to take it later at their own convenience.

As for the online sources, posts were made on the forum introducing the project purpose and asking for their participation in the survey. Finally, a Wikipedia article was created titled *"Nanotechnology Fail-Safes"* which introduced the research findings and the IQP team, as well as asking for their participation in the survey. Results were processed by a script within the site, and e-mailed to the group by use of a free script on the "Email Me Form" website.

Figure 4 – Nanotechnology Survey Reminder Business Card.

2.3 SURVEY PREPARATION AND DESCRIPTION

Prior to the development of the survey, the team first chose four areas for further research: mechanical, DNA/amino acids, antibiotics/proteins, and programming. Each team member took one of the four topics, and researched the current fail-safes that were being developed as well as proposed within that particular field. Upon the completion of the research phase, questions were developed regarding the level of acceptance for each fail-safe method. Following the suggestions in *How to Conduct Your Own Survey*, the team decided to narrow down the list of questions to twenty, choosing the five best questions from each category[19]. In balancing out the number of questions from each group, the group tried to ensure that no one topic will carry more weight than the others. The survey takes about ten minutes to complete, and at the end, the user is given the option to submit their e-mail address for a chance to win the previously mentioned prizes.

For the development of the survey webpage, the team divided up the material into several pages as to prevent the survey from being too overwhelming. Originally, the pages were being developed in Macromedia Dreamweaver, but after several issues with incorrect formatting, the entire page was recoded by hand. The layout of the page is

relatively straight-forward. After following the link to the survey, a brief introduction to nanotechnology is provided, as well as a link to the Wikipedia article. The user also selects which group of user they belong to from the list mentioned previously.

Prior to the questions regarding the research topics, it was important to understand the user's self-proclaimed knowledge of nanotechnology. Thus, the first two questions of the survey ask the user to rate their level of knowledge on a scale from 1 to 5, and whether or not they were aware that nanotechnology has already been used in some commercial products. The remaining three questions gauge the user's acceptance of mechanical fail-safes for a medical procedure or an accidental exposure to nanoparticles. These questions are all yes/no or rating-based and the distribution of each type is consistent across the four pages, with three yes/no and two rating-based questions on each page. The remaining three pages focus on the other three topics, determining the user's acceptance of DNA, antibiotic-based, and programming-based fail-safe methods.

A normalized scale was established to add equal weight to the positive and negative feedback. A response of 1 equals a rating of -1 meaning least knowledgeable or accepting, a 3 equals a rating of 0 meaning neutral or indifferent, and a 5 equals a rating of 1 being extremely knowledgeable or accepting. For a copy of the survey see Appendix C.

2.4 EXPECTED DATA TRENDS

As was the case in previous IQP projects, a correspondence between higher knowledge and higher levels of acceptance was anticipated. Taking that into account, the team also felt that the WPI community being more knowledgeable in technology as a whole would lead to the students and professors having a higher acceptance level than the

general public. The Wikipedia users are expected to be below the WPI acceptance levels, but slightly higher than that of the forum members. This is because Wikipedia users have read our Wikipedia article and probably will have a higher knowledge regarding nanotechnology than the general public, which may not have read the article.

There is no way of predicting which individual topic will be the most accepted. However, it seems likely that mechanical fail-safes could be favored methods, as they are the most controllable. On the other hand, antibiotics have helped almost everyone at one point or another, so the antibiotic aspect may also be very favorable. The acceptance also depends heavily on how much each area of focus has influenced the individual's life. Therefore predicting which fail-safe will be the most accepted is impossible.

2.5 METHOD OF ANALYSIS

The data collected will be analyzed in the four individual groups and by self-perceived knowledge levels. Analysis will consist of determining the overall trends across the various subgroups, while looking for the standout points of interest where a question's acceptance may vary greatly from the rest.

3. Results and Analysis

3.1 INITIAL RESULTS

An important aspect within this IQP project was conducting a survey. The objectives of this survey were to explore the risk level that the public associates with nanotechnology, as well as to determine which particular area of fail-safe methods are likely to convince people to be the most accepting to nanotechnologies. Another objective was to inform the public through an article on Wikipedia of the nanotechnology research results that include options of possible fail-safe methods.

The initial proposal of having a target population greater than a minimum of thirty people was met. The group surveyed 252 WPI students, 30 WPI professors, 52 people in a public forum, and 14 Wikipedia users. The results from the survey met a 95% confidence interval with +5% sampling error, both in WPI students and in WPI Professors. This sample size is a good representation of the WPI academic population. The confidence intervals for the Moola forum and Wikipedia populations are indeterminable because the total population size is unknown. Our data show an overall acceptance from 0.41 with students, 0.27 with professors, 0.33 with forum users, and 0.41 with Wikipedia users

3.2 INTERPRETING GRAPHS AND CHARTS

The figures shown below are laid out to show the collected data in a way that is clear and easy to interpret. Along the x-axis are the questions labeled 1-20, which correspond to the question being evaluated. Question one establishes the respondent's

self-proclaimed level of knowledge. Questions three through five inquire about our proposed mechanical fail-safes, while questions six through ten ask about DNA/amino acids fail-safes, whereas questions eleven through fifteen deal with antibiotic and protein based fail-safes, and finally questions sixteen through twenty have to do with programming fail-safes for nanotechnology.

The y-axis, labeled -1 to 1, represents the chosen level of acceptance. A response of -1 is interpreted that the user is very uncomfortable with the question, and a response of 1 is interpreted that the user is very accepting of the question. If a user's response is a zero that means that he or she is indifferent or undecided on the question being asked. In the case of question one of the survey, a -1 means that the user claims to have no knowledge on nanotechnology, a zero means average knowledge, and a 1 means the user claims to be extremely knowledgeable on nanotechnology.

Most of the charts include error bars which are ranges designated by points centered at the mean response. These ranges represent 1.96 expected population standard deviations from the mean response on either side. This range provides the 95% confidence interval for any given response, which means that for the given data we are 95% confident that any response to that particular question will be in that range[2].

3.3 ANALYSIS BY POPULATION

This section will be a brief comparison between the four separate target populations. This comparison will show the differences in responses with regards to the background of the target populations. The four groups all have different levels of education, and different motivations for taking the survey or viewing the Wikipedia article, which surely varied their responses. The thirty professors from WPI had the

lowest mean response of 0.27 over the entire twenty questions, meaning they were the least accepting group. This group was assumed to have the highest level of general education out of the four target populations, and not surprisingly they also had the highest self-proclaimed knowledge regarding nanotechnology. These data are conflicting with the data provided by breaking down the results into groups by knowledge level, which for the most part did support the hypothesis. The fifty-two Moola public forum users had the next lowest average response of 0.33. Unlike the WPI professors though, the data provided by these participants did agree fairly well with the hypothesis, as they were least knowledgeable about nanotechnology. The 252 WPI students and the 14 Wikipedia users had identical overall acceptance levels, both with 0.41. Their knowledge levels were quite different though, which again does not support the hypothesis. The four target populations have dramatically different participant numbers though, which may have an undesirable and inaccurate affect on the results when they are separated in this manner.

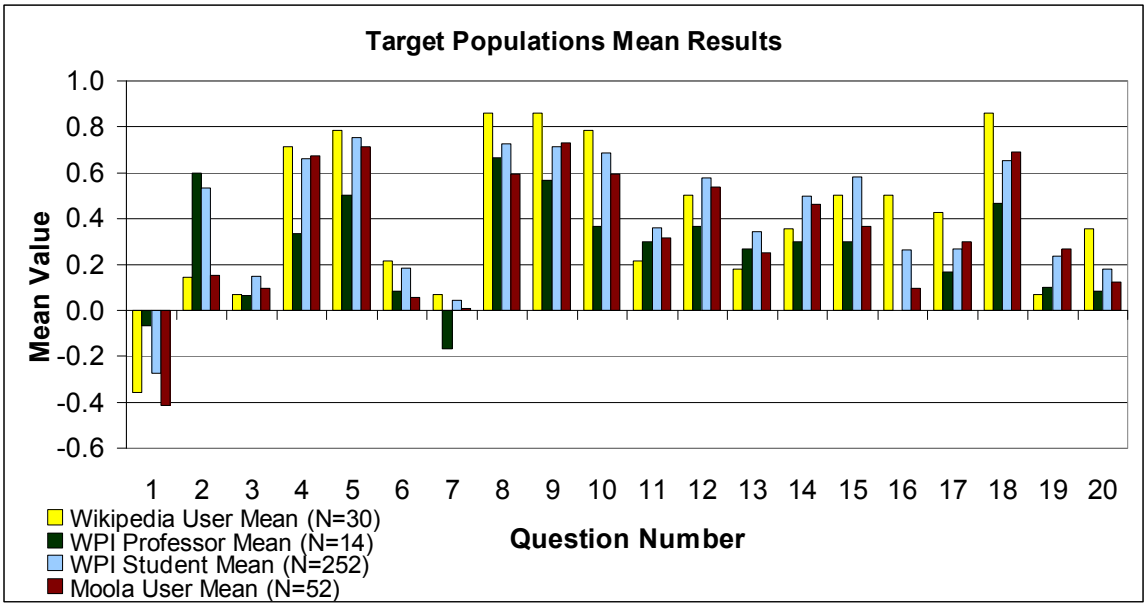

Figure 5 – Graph compiling the mean results of our four target populations.

3.4 ANALYSIS BY SELF-PROCLAIMED KNOWLEDGE

The initial way in which the results were analyzed by self-proclaimed knowledge was to divide the data up into the five knowledge levels and into the four target populations. These data were then plotted, on Figure 6 below, to clearly display the trends of the four populations with respect to knowledge. On the x-axis is self proclaimed knowledge based on the answer to the first question of the survey. The y-axis shows the mean of the answers to the nineteen other questions, zero being neutral, and one being very accepting of nanotechnology. The error bars represent a 95% confidence interval for the given responses to each question.

It can be seen that with all four of our surveyed populations the acceptance is higher when the user answered a five for self-proclaimed knowledge than when that person answered a one. The chart shows that even when knowledge was very low, most users were still slightly accepting of nanotechnology. The Wikipedia users line shows an interesting trend, as the acceptance started at 0.46 and dipped to 0.00 when self-proclaimed knowledge was a three, and finally reached 0.49 when knowledge was chosen as a five. This is most likely due to a very low amount of surveys recorded in this population, which allows for a higher potential for error in the data. WPI students showed a fairly consistent upward trend starting at 0.32 and reaching 0.55 when the user answered five. Moola users and WPI professors showed a somewhat consistent upward trend. The Moola results had an acceptance value of 0.34 with little knowledge, and 0.84 with high knowledge. The WPI professors showed values of 0.29 with low knowledge, and a value of 0.63 when a five was chosen.

The plot of the overall results demonstrates a fairly steady increase in acceptance over the knowledge range, with a slightly steeper incline at the middle than at the extremes. The plot has an acceptance value of 0.33 with little knowledge, and 0.61 when the users answered a five. The linear best fit of this line shows clearly shows a positive slope at which acceptance changes with knowledge. The equation for this linear best fit line is $Y = 0.069X + 0.257$, with a correlation coefficient of $R = 0.968$. Figure 6 does support the team's hypothesis, in that the level of acceptance does in fact increase as the level of knowledge of nanotechnology increases.

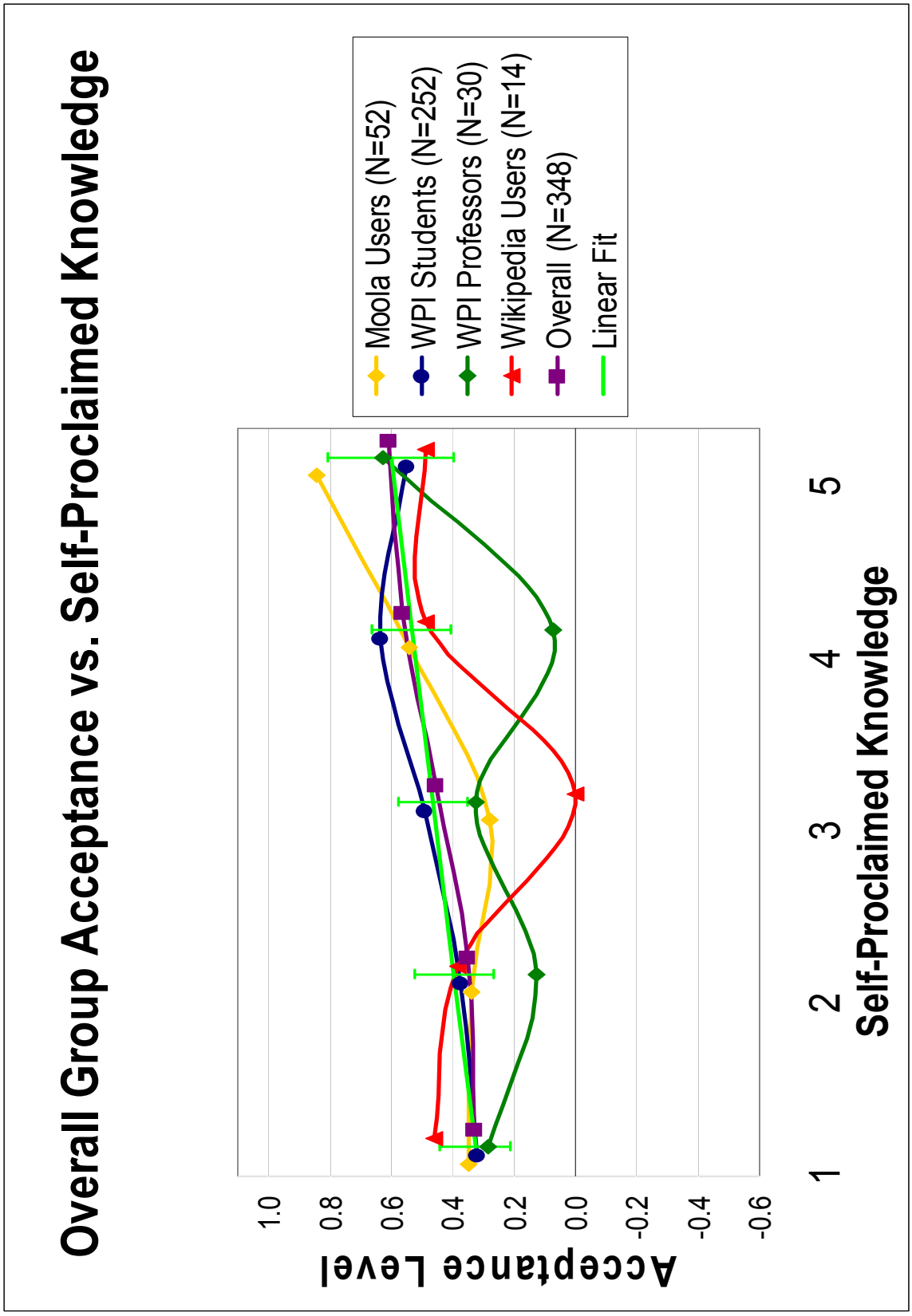

Figure 6 – Graph demonstrating acceptance increasing with self-proclaimed knowledge.

For the major analysis by self-proclaimed knowledge, the mean responses to the twenty survey questions for the entire target population will be split into five charts (one through five) based on their answer to question number one. There is also a sixth chart which incorporates all five plots on one chart. These charts are figures 7 through 12 and are located at the end of this section. A one, which is equal to a -1 on the y-axis, means the participants were the least knowledgeable, and a five, equal to a 1 on the y-axis, means they were the most knowledgeable. These responses will be compared and contrasted with each other in order to prove or disprove our original hypothesis of stating that a greater knowledge about nanotechnology will result in a greater acceptance of nanotechnology.

The results to question two do not provide any insight into acceptance, but very clearly reinforce the responses to question one. For those who answered a one for question one, the majority of people did not know nanotechnology was currently being used in consumer products. For participants who answered with a two or three regarding their knowledge, the amount who knew about the use of nanotechnology in consumer products rose respectively and was now the majority. Those who answered with either a four or a five for question one all knew that nanotechnology was already being used in consumer products. The error bars add additional strength to this trend, as there is very little overlap between successive knowledge level ranges.

Question three concerning the breathing of nanoparticles revealed perhaps the best evidence to support our hypothesis. The results showed that those who answered a one on question one were the only group that had a negative mean value, meaning they were uncomfortable with the concept. As the knowledge increased, the acceptance of the

idea presented in question three escalated respectively in a progressive fashion up to a value of about 0.87. This clearly endorsed the IQP hypothesis for a very relevant situation involving nanotechnology. While the error bars for the ones and twos are nearly identical, there is no overlap whatsoever for the twos through fives. This confirms that acceptance for this question does increase for higher knowledge levels.

The fourth question involving the injection of nanoparticles into the body revealed a pattern not so supportive of our hypothesis. For those who answered a one through three on the first question, the results from question four are so close that they are nearly statistically the same, ranging from 0.61-0.63. However, the people that answered a four were most accepting at 0.75, and those that answered a five were somewhat less accepting with a value of only 0.40. While this does not follow the hypothesis, all groups were at least moderately accepting of nanotechnology in the given situation. There is no discernible trend in the error bars for this question. However, overlap between the ranges indicates group five's true mean may still be the same as the others.

Question five results displayed a moderate to high level acceptance from all knowledge groups, but does not do so in a way that could either prove or disprove if acceptance is dependent upon knowledge for nanotechnology. Those who chose a one for question one were more accepting than those who chose a five. However those who chose a four were more accepting than those with a knowledge level of two. The most unusual aspect though, was that the people with a three for knowledge regarding nanotechnology were the most accepting in this case.

Question six provided results very close to what we were expecting for this IQP. While the acceptance of nanotechnology was only minor, with values ranging from 0.04-0.33, the pattern of these values was very useful. The values for the knowledge groups one through five were respectively: 0.04, 0.05, 0.23, 0.32, 0.33. This illustrates just the slightest positive acceptance for those who considered themselves not knowledgeable, and then shows a large jump of 0.18 to the values of those people with average and above average knowledge about nanotechnology.

The seventh question, a question regarding the use of DNA in nanotechnology, also provides a quite good argument for our hypothesis. The values for this question do not display a linear correlation between knowledge and acceptance, as the response from the second knowledge group is lower than the one's for knowledge, and the same is true for the fourth versus the third knowledge group. However, both the groups who answered a one or two for question one were not accepting of nanotechnology in this case, while those who answered a three or four were slightly accepting, and those with a knowledge level of five were rather confident with the situation.

Question eight provided results very similar to question four, where the people who were a one through four for their knowledge had very like responses to question eight, and those who were a five for knowledge were still accepting, but much lower on the scale. Unlike question four, this question did not involve nanotechnology, but rather just inquired about the willingness to take a pill in a procedure, therefore these results are not necessarily conflicting with the hypothesis. As a side note, during the survey process some commented that they were confused about the true meaning of the question because of the incorporation of the phrase "for the purpose of saving your life." This may have

had some unintended influence over the responses to this question. The error bars lack any overlap between group five and the others, confirming that group five is truly the lowest acceptance for this question.

A very similar dilemma occurred with question nine as in eight, because this question also incorporated the phrase "for the purpose of saving your life." The results for this question were much more typical though, showing for the most part a rise in acceptance with a rise in knowledge. This question, like question eight, was not designed to test the hypothesis though, but was rather intended to test whether it was the nanotechnology that people feared in the given medical procedures, or if it was rather just the procedure itself. Since the overall acceptance of the two procedures given was moderate to high, the fear factor of the procedure itself can essentially be neglected.

Question ten supplied very promising results for this IQP. All five knowledge groups were at least moderately accepting of nanotechnology in the given situation. For the most part, the results showed an increase of acceptance with an increase in knowledge. Remarkably, every person who considered themselves to have the highest level of knowledge about nanotechnology was accepting of the procedure involving the bio-compatible nano-medical device.

Questions eleven and twelve both dealt with similar situations, in that nanotechnology was incorporated into common preexisting medical methods. The results for these questions were both good positive responses, however the range of responses was quite different. Question eleven had a very large range from 0.22 for those with a knowledge level of two, up to a 1.00 for those who with a knowledge of five. Question twelve was much more localized with responses only ranging from 0.45-0.65. Question

eleven included antibiotics as a much more specific aspect, where as question twelve was designed to be fairly vague. While both questions did for the most part show an increase in acceptance with an increase in knowledge, the more specific question provided clearer results.

The thirteenth question inquired about the acceptance of the use of synthetic proteins in the body. This question presented very sought-after results in that there was a very linear increasing correlation between knowledge and acceptance of nanotechnology. The only exception in this sample is that the acceptance from the level one knowledge people is higher than from the twos. Conversely, for the twos, threes, fours, and fives, the acceptance ascends by approximately 0.15 with every increase in knowledge. This question does involve nanotechnology, but does not use the word nanotechnology anywhere in the question itself. This may have been partially responsible for such a positive response. Nevertheless, this question does help to support our hypothesis for this project. The error bars add further support to our hypothesis, with an upward trend, and very little overlap between groups.

Questions fourteen and fifteen posed very similar situations regarding the use of nanotechnology for therapeutic purposes, with the difference being that in fourteen the nanoparticles could be disabled if need be, and in fifteen they were only monitored in the body. As expected, these two questions bestowed very similar results; and they are indeed results that do support our hypothesis. Unexpectedly though, question fifteen had a higher positive response than fourteen, despite the fact that it suggested a less assured fail-safe. The only other difference between the two questions was that fourteen used the term “synthetic protein” where as fifteen only used the word “protein,” which was most

likely the cause for the response discrepancy. The error bars for both questions confirm the higher knowledge groups are more accepting, but are too close in value to determine whether a trend for threes through fives exists.

Question sixteen inquired about a remote control vs. a pre-programmed method regarding nanotechnology. The knowledge groups one through four had responses very close to zero, meaning that there was no significant preference for either method. Interestingly though, the fifth knowledge group had an average response of 0.67, meaning that they heavily favored a remote control option. This question was designed only to determine which method of the two suggested would be more socially successful in the event that nanotechnology was executed in human medicine in the future.

The seventeenth question investigated people's comfort with the use of nanotechnology programmed for the treatment of diseases. The overall acceptance was positive, however, the responses did not follow a trend consistent with our hypothesis. The fifth knowledge group was actually the least accepting with an average response of 0.13. Question twenty, was a very similar question to seventeen, with the difference being that the nanotechnology was still programmed but not necessarily programmed to fight diseases. This question displayed results with an almost identical trend to seventeen, with the level five knowledge group answering a zero for this question. Although these two questions do not support our hypothesis, they do show that similar questions result in similar responses which definitely strengthens the validity of the survey given.

The responses to question eighteen are very localized only ranging from about 0.60-0.71, which is not enough differentiation to determine any considerable trend in the data, not to mention it is the extremes of the knowledge groups that are the most

supportive of the given situation. This question focuses more about a particular procedure however, than it does about the use of nanotechnology. The purpose of this question, as is also the case for question nineteen, is determine the public level of comfort with certain procedures that would be associated with nanotechnology. The data from question nineteen was more decipherable than eighteen, yet similar to eighteen, the two most accepting groups were the two extremes of knowledge. The useful information inferred from these two questions is that if nanotechnology was incorporated into human medicine, more people would support a specialist controlling the procedure rather than a computer program. There is some controversy regarding the data from question nineteen though, because much like questions eight and nine, the phrase "for the purpose of saving your life" was used which was may have made the question unclear for some participants.

For a more in-depth comparison between the four target populations regarding knowledge about nanotechnology see Appendix D.

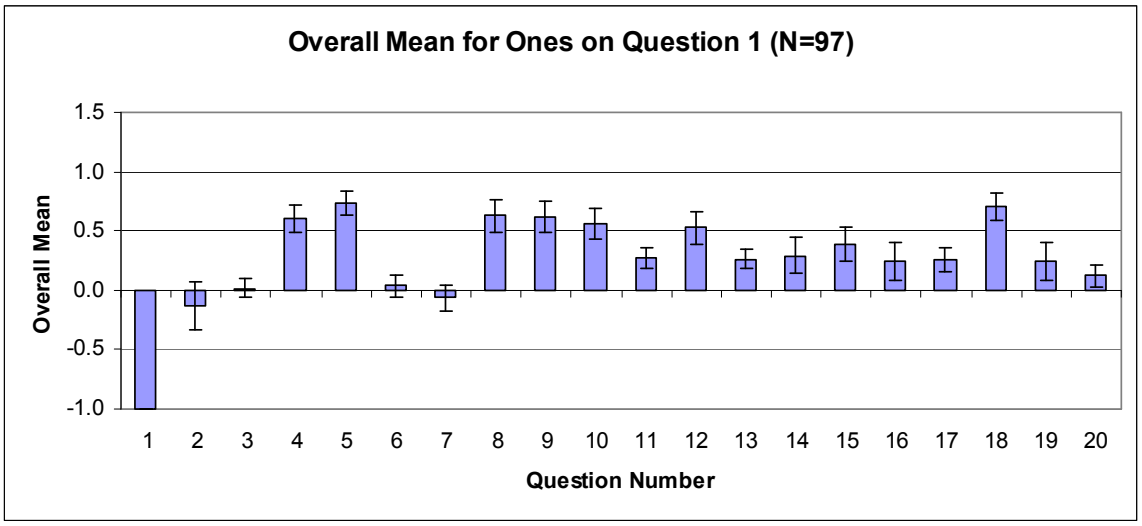

Figure 7 – Results from the least knowledgeable population.

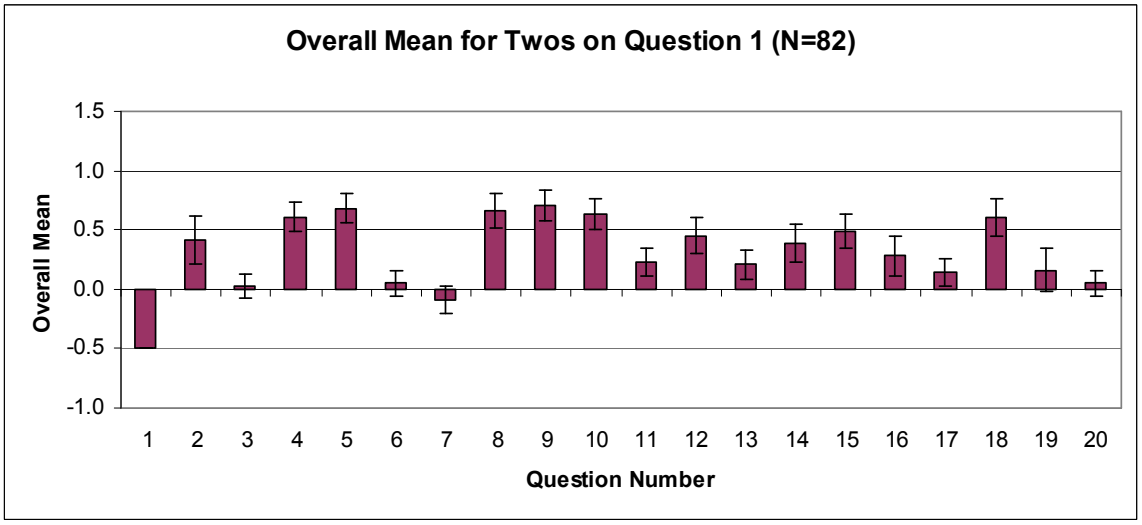

Figure 8 – Results from the population with low self-proclaimed knowledge.

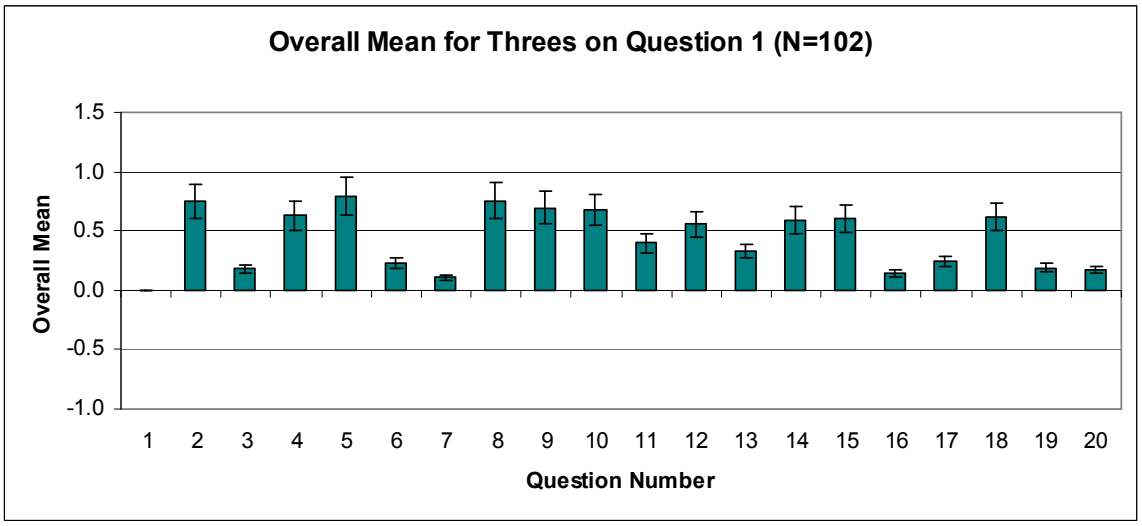

Figure 9 – Results from population with average self-proclaimed knowledge.

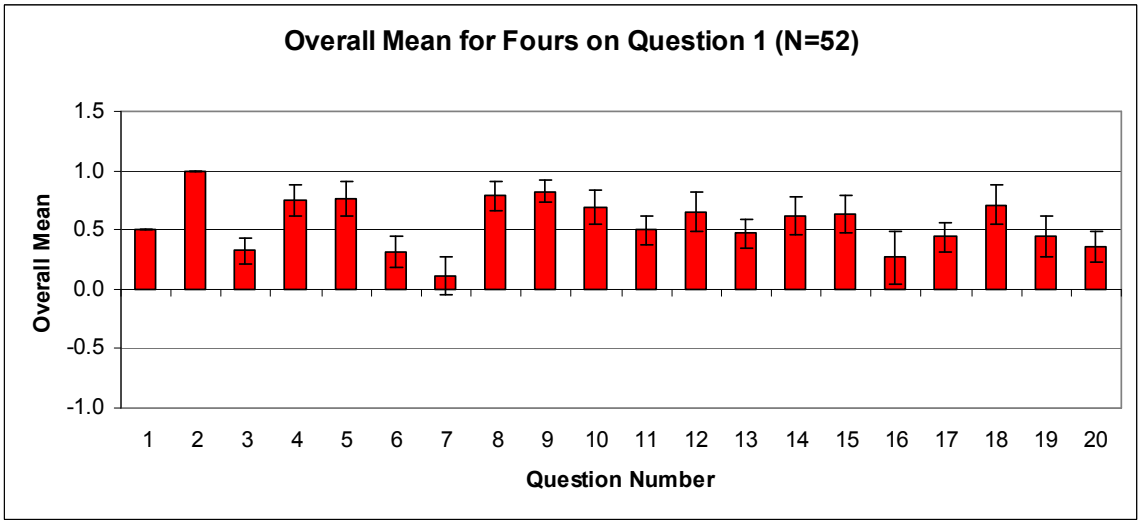

Figure 10 – Results from somewhat knowledgeable population.

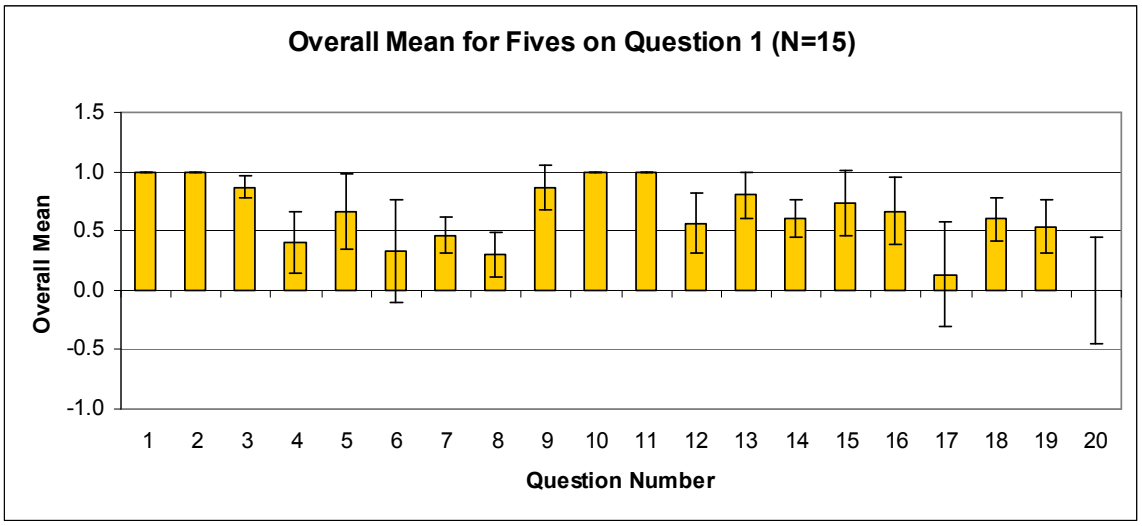

Figure 11 – Results from the most knowledgeable population.

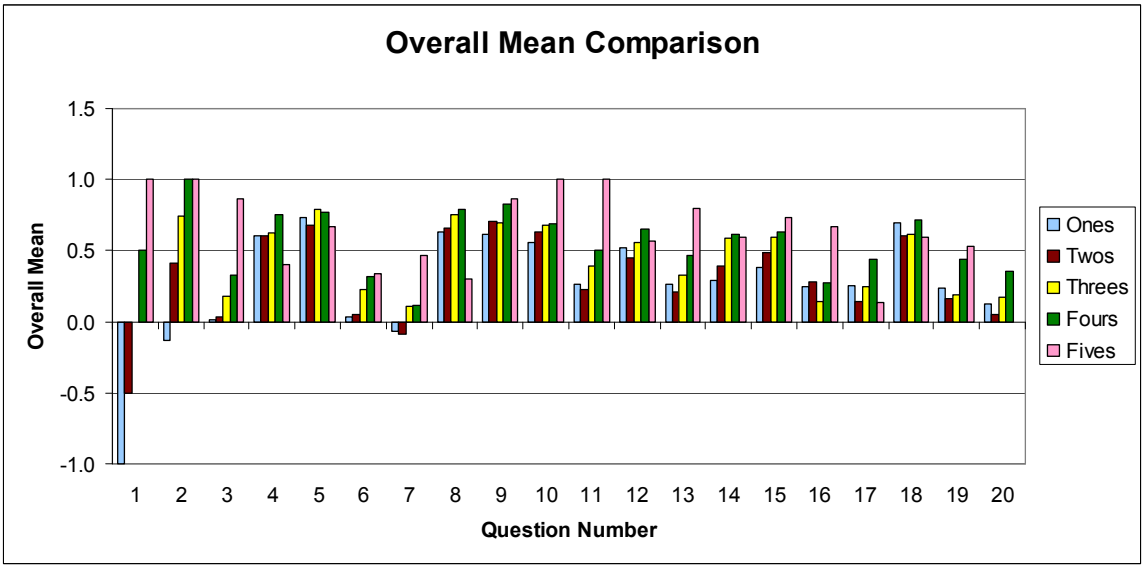

Figure 12 – Compilation of self-proclaimed knowledge from all populations.

4. Conclusions and Future Recommendations

4.1 CONCLUSIONS

The survey for this IQP project was established to determine whether self-perceived knowledge levels played a significant role in the overall acceptance of nanotechnology in today's society. The collected data proved that there is an overall trend in levels of acceptance, broken down by knowledge level, gradually displaying higher acceptance rates as knowledge levels increase, therefore proving the team's hypothesis.

Considering such trends with regards to the overall acceptance as well as individual fail-safe acceptance levels could allow researchers to more successfully develop their products because they would meet less opposition. Incorporating highly favored fail-safe topics such as automated sensors, biocompatible materials, contemporary pharmaceuticals, or the use of nanotechnology specialists would certainly improve social acceptance. An alternative approach would be to promote the fail-safe areas which portray lower general acceptance levels. Two-layer programming which includes a remote controlled aspect, DNA and amino acid based nano-structures, and airborne nanotechnology were areas that were not highly accepted. However, promoting these aspects might improve public knowledge, acceptance, and interest in nanotechnology as a whole. Regardless, researchers should begin developing their products to the specifications which would most likely meet public acceptance, while still within the limitations of the product.

This IQP team's first goal was to research current nanotechnology fail-safe developments. That portion of the project was achieved by initially reading "Scientific

American Reports: Special Edition on Nanotechnology", and investigating the content of those articles further. The second goal was to inform the public about nanotechnology fail-safes. A Wikipedia article was published, seen in Appendix B, that draws the research topics together. It allows everyone to access our findings, successfully completing the second goal. Finally, the third goal was to determine the effects of self-proclaimed knowledge on the acceptance of nanotechnology fail-safes. An online survey investigating this subject was conducted to complete our final goal.

The overall mean for each knowledge level was used to determine the best-fit linear equation of acceptance as a function of self-proclaimed knowledge. Those values were 0.331±0.116 for ones, 0.353±0.130 for twos, 0.455±0.113 for threes, 0.562±0.128 for fours, and 0.607±0.204 for fives. From these values, the calculated best-fit equation (as seen in Figure 6) for overall acceptance was $Y = 0.069X + 0.257$ with an R value of 0.968, where X is the level of self-proclaimed knowledge and Y is the overall acceptance. This linear best fit line was the strongest evidence supporting the increase of social acceptance of nanotechnology with an increase of self-proclaimed knowledge.

4.2 FUTURE RECOMMENDATIONS AND RESEARCH

As with every Nanotechnology IQP project, there are problems that arise and lead to future recommendations. This year's project was no exception. Difficulties with user participation were encountered in the WPI and Wikipedia communities, as the motivation factor for completing the survey was extremely low, even after presenting possible prizes for their survey participation.

One of the major issues that came about was the inability to access a sufficient WPI population base. Many WPI students and professors were unavailable to take the survey because of their schedules or previous obligations. Consequently, the IQP team recommends that future teams attempt to incorporate the WPI Alumni into their potential survey groups, to extend beyond the core WPI community. A second recommendation pertaining to the WPI community is to produce business cards or equivalent, featuring the core project details, and providing the recipients with any necessary survey information required for their participation. Finally, it is advised that future groups be more persistent in that they resort to other methods of promotion, beyond simply handing out cards in the Campus Center. Going door to door, promoting in individual classes, and even requesting professors to e-mail all of their students proved to be crucial in the IQP team's ability to meet their target populations.

The Wikipedia population presented its own set of similar problems. One of the problems that must be taken into account by future IQP teams incorporating Wikipedia into their project is the simple fact that any user can modify the page as they see fit. Proper grammar seemed to have been a key factor with heavy influence on the modifications made to the team's page. This IQP team highly recommends taking any possible Wikipedia article to the Writing Center several times. Looking into the rules regarding article content is another crucial step, as several of this team's errors could have been avoided with a little research into proper article guidelines.

Finally, to promote survey participation, incorporating more immediate incentives would likely improve the probability of students and professors spending their free time participating in a survey. Several of the team's experiences while trying to gather survey

results have proven that having food at your station would greatly improve the amount of attention in the team's general direction. This year's IQP team strongly advises that all future IQP projects follow the steps above to improve the overall efficiency in the data collection problem.

While previous IQP teams focused primarily on the level of acceptance of existing technologies already being incorporated into society, this team suggests that the continuance of a more active project orientation will produce more effective and useful results in the future. By determining which areas of research in nanotechnology are likely to garner higher levels of general social acceptance, future groups can potentially promote further research in those aspects, or even improve the acceptance of the less favorable fields.

Appendix A

Social Acceptance of Fail-Safe Nanotechnology

PROPOSAL FOR AN INTERACTIVE QUALIFYING PROJECT

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

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Aaron Costello

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Justin LeBeau

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Robert Warren

Date: October 16, 2008

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Dr. Nancy A. Burnham, Major Advisor

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INTRODUCTION: Nanotechnology Fail-Safes

Nanotechnology is defined by NASA as the creation of functional materials, devices and systems through control of matter on the nanometer length scale (1–100 nm), and exploitation of novel phenomena and properties (physical, chemical, biological, mechanical, electrical...) at that length scale[i]. The concepts of nanotechnology first emerged in a talk by physicist Richard Feynman titled "There's Plenty of Room at the Bottom" during an annual American Physical Society meeting at the California Institute of Technology on December 12, 1959. This was fifteen years before the term "nanotechnology" was coined in a paper titled "On the Basic Concept of *Nano-Technology*," by Norio Taniguchi, a Tokyo Science University Professor[ii]. It was not until 1989 however that nanotechnology received wide-spread interest when IBM used a scanning tunneling microscope to depict the company's corporate logo on a piece of nickel with 35 xenon atoms[iii]. Currently, almost twenty years later, nanotechnology is being used in a wide range of consumer products from personal computers to tennis racquets. Thus far modern applications have only implemented fixed nano-structures. The frontier of nanotechnology will most likely lie in automated nanobots, biological nano-machines, and computer processing technology.

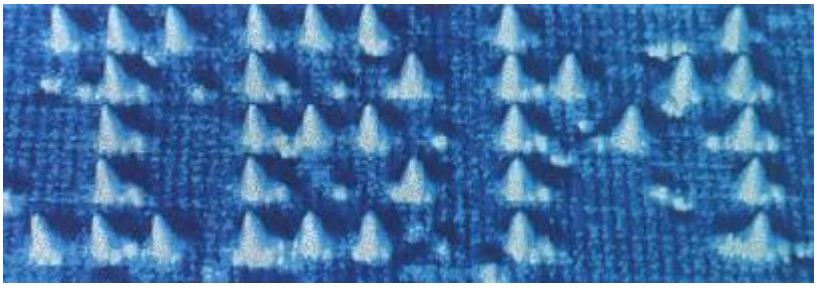

Figure 1: IBM uses 35 xenon atoms to write corporate logo[iv]

The emergence of nanotechnology has created a new realm of ethical issues and public concerns to address. Wade L. Robison, a professor at the Rochester Institute of Technology has organized the sources of potential problems into five categories: invisibility, micro-locomotion, self-replication, behavioral unpredictability, and ontological status[v]. The very plausible possibility of unforeseen problems leads to logical public fears of the new technology. It is evident that some action must occur in order to secure public and government approval for the further development of nanotechnology. A reliable method for avoiding potential problems is also a necessity when requests for outside funding are essential to research. One way of avoiding potential problems is the implementation of fail-safes into a process. A fail-safe would stop a problem before it could proliferate, or eliminate the problem all together.

A fail-safe is something designed to work or function automatically to prevent breakdown of a mechanism, system, or the like[vi]. The IQP group has categorized all current fail-safes into four methods: biological, mechanical, programmable, and electrical. There are currently multiple fail-safe concepts within each of the four methods that could be applied to nanotechnology (Appendix A). Many of these concepts are currently being researched and developed worldwide; while others, such as nanoparticle detection, monitoring and characterization techniques within industry are already being applied[vii]. These fail-safe processes, the team believes, will make the advancement of nanotechnology harmless enough so that it may be feasible and practical to do so; as well as inspire enough confidence regarding the technology to gain the necessary public support.

IQP GOALS

The primary goal of the IQP project is to inform the public as to what the research in nanotechnology yields for possible fail-safes through an article on Wikipedia. This research will be performed in different areas such as, biological, mechanical, programmable, and electrical. The secondary goal of this IQP project is to study these research areas which have fail-safe implementation capabilities and could stop nanotechnology from getting out of control and essentially causing harm. The third and final goal of this IQP project is to conduct a survey in order to determine which fail-safes would be most easily accepted. The objectives of this survey will be to explore the risk level the public associates with nanotechnology, as well as to determine which particular area of fail-safe would make people the most accepting of nanotechnologies. In addition the survey will determine whether, the fail-safe that the individual chose would make them in favor of nanotechnology.

PREVIOUS RESEARCH

The goals of this project are based from the understanding of the past IQP projects, as well as built upon their conclusions. Thus, a short overview of what the past groups accomplished is needed.

The first IQP project entitled "*Will Prey Consume Nanotechnology?"* concentrated on the idea that public fears of nanotechnology could be so extensive that they might delay or even inhibit development of the science. The project members observed and analyzed the extent of public knowledge and fear of nanotechnology that exists in modern society via a local survey and the data from previous surveys conducted by outside sources. The team concluded that only a small portion of the public are informed of what nanotechnology entails. The general public who has lesser education on the subject seemed to be much more accepting of the science. Once

these people were informed that some of the items which they use everyday already incorporate nanotechnology, they seemed even more accepting. However, the Grey Goo theory was a still a strong fear in even the more knowledgeable individuals surveyed. The Grey Goo theory is of nanobots designed to build other nanobots or replicate themselves, leading them out of control. It seems that support for any sort of building, and especially self-reproducing, nanotechnology is not in the near future[viii].

The second IQP project entitled *Social Acceptance of Technologies* focused on comparing three technologies; nuclear energy, genetically modified organisms, and vaccinations. It is shown how both genetically modified foods and vaccines are decided upon a personal level, and that people had fears that they themselves could be harmed by the technology. On the other hand nuclear energy the fear was on a different level. People saw what nuclear energy can do when used in war, and what damage it can cause when disasters happen. The group was then to compare these three technologies to nanotechnology, and the research showed that the perception of risk vs. benefit was the most important factor in determining social acceptance of nanotechnology.[ix]

The third IQP project entitled *Social Acceptance of Nanomedicine* discussed researched the decision-making process in humans, showing the acceptance and social impact of nanomedicine. The main observation was the decision-making process is governed by several parameters, each contributing to the conclusive decision. With that finding, the primary goal of the project was to determine the main three influential parameters that direct such a decision. The third IQP group showed an acceptance of medication containing nanoparticles that is related to other factors such as, price, efficiency of the medicine, clinical trials of vaccines, and friends or family advice, are left unchanged. It was observed that as soon as another factor was introduced,

the respondents became non-accepting, no matter what their risk type was. An interesting finding of the study was when the medication was cheaper and it contained nanoparticles, the moderate respondents went to the other extreme, being the ones that were the most denying, followed by the safe and the risky, who were less denying[x].

The fourth IQP project entitled *The Effect of an Educational Video on the Acceptance of Nanotechnology* hypothesized that showing an educational nanotechnology video would improve the acceptance of nanotechnology. The team used an internet-based educational video and a set of surveys to collect data on the resulting acceptance of nanotechnology after viewing the video. For the data analysis, comparisons between majors, gender, college, and overall trends with the general acceptance and acceptance of specific types of nanotechnology were made. A survey was given to the audience before and after the video asking the viewers to rate their level of concern on various aspects of nanotechnology. The data collected by the group, disproved their hypothesis; showing that after watching the educational video, acceptance of nanotechnology was actually less. This was an especially surprising outcome because most of the target population for the project was engineering college students; the people who will soon be leading fields of new technology. This outcome yielded an entirely new task; how to educate the public about nanotechnology without generating additional fears[xi].

Although the conclusions of previous IQPs are significant, their research only focused on the acceptance of nanotechnology. The questions in the surveys touched upon nanomedicine and nanotechnology in general, but what would make society accept these technologies was not found. In addition, the previous IQP findings implied that society would accept nanotechnology if certain factors are met.

These findings were the principal motivations for focusing this IQP on fail-safe methods

for nanotechnology. In addition to the previous IQP's, other background research was conducted by this IQP team. Fail-safe devices do exist in today's science which could be implemented into the nanotechnology world. These fail-safes varied from biological solutions to computer science solutions. The common theme which was associated with these developments was that they were all man made, minimizing outside factors of nature. A better foundation regarding fail-safe principles and devices is established in Appendix A.

This IQP will focus on applications of fail-safe ideas, based on literature, for different fields of nanotechnology. The project will explore possibilities of a fail-safe that can stop nanotechnology from getting out of control and causing harm. The methods in which the project is going to be pursued is described in more detail in the IQP goals section.

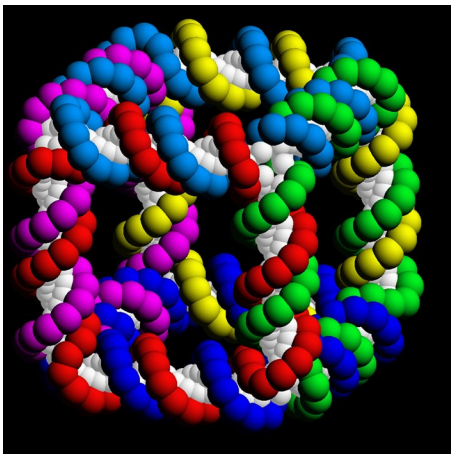

Figure 2: A stick cube made out of six loops of DNA demonstrated that three-dimensional structures can be built.[xii]

IQP SURVEY

In the survey, two of the three IQP goals will be obtained with a Nanotechnology Fail-Safe webpage in the form of a Wikipedia article and online survey. The survey will be based on the public acceptance of nanotechnology and the execution of various fail-safes. The Wikipedia article will inform the general public of the ways in which unanticipated problems can be avoided or stopped with the use of certain fail-safes. The webpage will include a counter that

records the number of people which view the article. The counter will help determine the effectiveness of the webpage and the level of interest in nanotechnology fail-safes. The webpage will also contain a direct link to the survey.

The survey will consist of twenty questions that establish how willing and comfortable people are with the development of nanotechnology which has the fail-safes in place. A tentative list of these questions can be found in Appendix B. Individuals participating in the survey will be divided into four groups in support of better analysis of the data. The data from each group will be analyzed separately and then compared against the other three groups. The survey will be in the form of multiple choice questions, asking specific questions about particular aspects of nanotechnology fail-safes. Before each set of affiliated questions, there will be a brief introduction giving the background necessary to answer each question appropriately. The survey will be conducted online only, if necessary a computer will be provided to the respondent.

Based on the reactions of the people to the Wikipedia article, as well as their answers to the survey questions, the IQP team will attempt to determine if the current possible fail-safe methods would be sufficient, to make the average person comfortable with the further development of nanotechnology.

TARGET POPULATION

To achieve statistical value, the team will use a book which was used by previous IQP groups called *How to Conduct Your Own Survey*.[xiii] The collected data will help reach conclusions that can be used by other researchers or companies; a large target population is going to be surveyed with a breakdown into four groups. The goal is to survey a minimum of thirty people from each of the fallowing groups; WPI academic personnel, WPI students, general public (forums), and Wikipedia users. This will provide a target population of various

backgrounds in education, professions, and personality types. Having the survey population broken down into four groups will show the significance of each group in society, as well as ensure that if the data is inconclusive from one group, data could be collected from another.

In order to attract members of the target population to complete the survey, the team will offer prizes or gifts, which will hopefully provide sufficient incentive. The incentives will also be broken down into the four groups, as different groups may be interested in different incentives. In order to interest academic personnel, members of the IQP group will be going to professor's offices with baked goods or other foods and offer an item in exchange for the competition of the survey. To entice WPI students to take the survey, the group will record each student's email address for selection, and offer a ten dollar Dunkin' Donuts card.

The online forum to be used is www.moola.com because it attracts users who are online primarily to play games and not for any other specific reason, which will provide an eclectic background of many different populations. On this forum simple games are played by risking fake money in the form of Moola points. Once ten dollars worth of these points are accumulated, the user can cash those points out to receive actual currency. The team will offer a ten dollar Moola point award for the first place winner, six dollar price for second, and four dollars for third, the winners will be selected at random.

Wikipedia users will be provided with a link to the survey at the end of the article. Once the respondent reaches the survey website, it will be stated that if the user's email is entered at the end of the survey, then they will be entered into a lottery for a prize. The prize will be an item of WPI merchandise from the on campus bookstore.

TIMELINE

The proposed timeline is set up to maximize time available for the data collection process. The survey site and Wikipedia article will be up by the first week of November, providing about three and a half weeks of data before preparation for the B-Term presentation. The preliminary results will be presented to a group of professors at the end of B-Term. Data collection will continue through to the end of winter break, with data analysis ending in the fourth week of C-Term. Rough drafts will be composed throughout C-Term, incorporating the final results from the data analysis about three weeks from the end of the term.

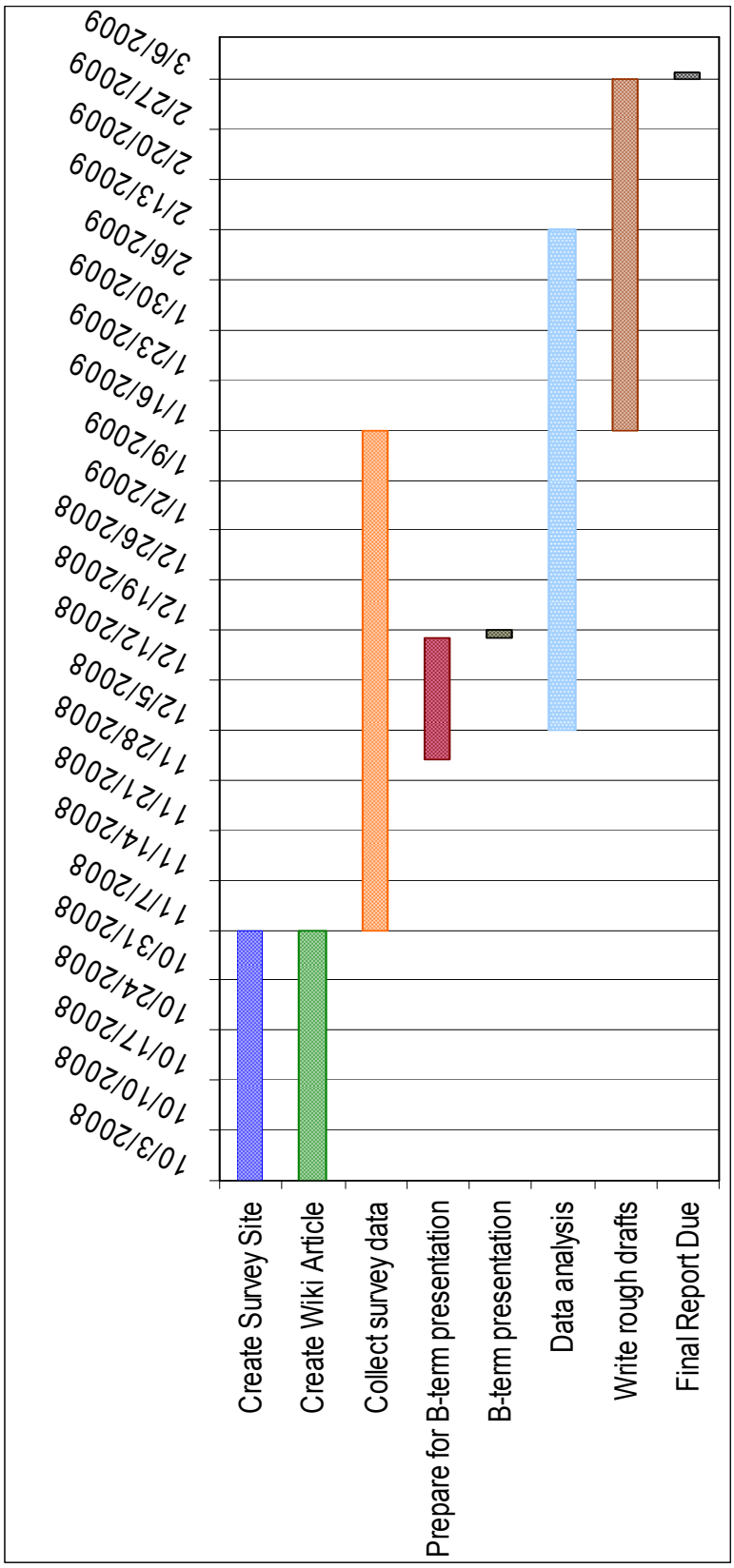

Figure 3: Gantt chart of Timeline

SUMMARY

Nanotechnology is one of the most promising fields of research in the world today. The applications of this growing technology are unbelievably diverse, with promising possible uses in almost every product market out there today. The one thing preventing an explosion in nanotechnology research and development, is social acceptance. The team members of the IQP believe that the public needs to be informed as to what fail-safes can be incorporated into the field of nanotechnology. Without further education, the public fears will control the market, leaving little room for nano-devices in everyday life.

By providing information regarding both theoretical and implemented fail-safe designs, public fears could be eliminated, or at least, greatly reduced. Through the continued introduction of informative websites, educational videos, and thought-provoking surveys, social acceptance would increase to a much higher level. By collecting data from the respondents, the group expects to propose possible fail-safe ideas that would create a greater level of social acceptance of nanotechnology. The further development of nanotechnology depends on this public education in order to gain a potentially solid footing in the world's technology market.

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APPENDIX A

What exactly does the term fail-safe mean? According to the Merriam Webster Dictionary, to fail-safe something means *"incorporating some feature for automatically counteracting the effect of an anticipated possible source of failure"*. A fail-safe by that definition is simply a device or means of operation, set in place to reduce the chances of a total system failure. While there has not been much research into the fail-safe techniques for nano-devices, it is quite possible to scale down current macro-scale fail-safe devices for applications at the nano-scale.

Some examples of general fail-safe devices and techniques are:

- Some machines use ignition kill-switches that require active human interaction or a tether in order for the ignition to remain engaged, such as personal watercraft or lawnmowers.
- Air brakes on trains and trucks. If a brake line is severed, the brakes are automatically activated as the pressure holding them open leaks out.
- Traffic light control systems can detect conflicting green-light signals, and will then display all reds as a countermeasure.
- Some safes use a pane of glass that will shatter if a thief attempts to drill into the safe. When this glass shatters spring loaded steel rods being held back by the glass are able to slide in place preventing the safe from being opened.
- Otis Elevator Company designed a special mechanism that would lock the elevator car in place if the hoisting cables were to fail.

Nanotechnology would be able to apply some of these fail-safes in order to make nano-devices safer. Some of the possible applications of fail-safes would be as follows:

- Automated sensors could be utilized in air ventilation systems to detect the presence of nanoparticles and react accordingly to ensure health of individuals.
- A small EMP could be used, as well as an MRI, to destroy nanobots injected into the body, should they malfunction. Either technique induces a large electromagnetic field, scrambling the memory and shorting out the circuitry of any electronic within range.
- Antibiotics are currently used to fight diseases once they have entered your body. With a bacterial nanobot "programmed" to perform a specific task, a pill could be taken to target and eliminate the bacteria should it get out of hand.
- With a DNA-based nano-device similar to the one above, proteins could be injected into the body to break down the DNA and render the device useless in the event of a malfunction.

APPENDIX B

TENTATIVE IQP SURVEY

Nanotechnology involves the use of particles only a few nanometers in size, that can be made from many materials such as metals or carbon. There are possible ways to prevent these particles from getting into the body unintentionally, and also ways to manipulate them in the body if necessary.

1. How knowledgeable do you consider yourself to be regarding nanotechnology?

2. Were you aware that nanotechnology is already used in some consumer products?

3. Nanoparticles can be airborne and get into your body in a number of ways. Would you be comfortable breathing air in a building producing nanoparticles, if there were prevention methods in place to stop the diffusion of these particles throughout the air?

4. If there were a medical procedure to save your life that involved injecting ferrous nanoparticles into your body, would you be comfortable with the procedure knowing that a magnetic field could be used to disable the particles?

5. Would you be more comfortable with the development of nanotechnology, if there were automated sensors to detect and warn you of harmful levels of nanoparticles in your surroundings?

Today's research in nanotechnology consists of: amino acids, DNA, programming, and molecular engineering. All of these methods are made so that they are bio-compatible and are harmless to the human body.

6. Modern day researchers are trying to create structures using man-made **amino acids**, which could be introduced into the human body. These structures can be tagged to specific molecules, enabling the capability of an on/off switch; in essence, a fail-safe feature to protect the user. As a consumer, how comfortable would you be to have such a device circulating in your body?

7. How comfortable would you be to have to take a pill to begin or stop a medical procedure, for the purpose of saving your life?

8. Scientists are currently trying to create structures using **DNA**, which could be introduced into the human body. These structures may be taken apart using proteins enabling the capability of an on/off switch. In essence, a fail-safe feature to protect the user. How comfortable would you be, to have such a device circulating in your body?

9. How comfortable would you be, to have an injection be a part of begin or stop a medical procedure, for the purpose of saving your life?

10. Would you be wiling to have a nano-medical device made of bio-compatible material circulating in your body, knowing that there is a safe method to take it out of the body?

Antibiotics have been used for nearly 100 years as a chemotherapeutic agent; chemicals with which to kill microorganisms in the human body such as, bacteria or fungi. Antibiotics or similar chemotherapeutic methods could also be used for the control or abolition of nanoparticles in the body.

11. Would you be accepting, in the intent for nanotechnology, of the use of new antibiotics for medical purposes?

12. Would you be comfortable with the use of nanotechnology for therapeutic purposes, within your body, knowing that a chemotherapeutic fail-safe is available in the case of an unexpected complication?

Biological proteins with in the human body perform three main functions: as structural building blocks, enzymes, and cellular signaling. Synthetic proteins could be used as enzymes or biological signalers for the purpose of monitoring or breaking down nanoparticles in the human body.

13. Would you be accepting of the use of synthetic proteins, in your body for medical purposes?

14. Would you be comfortable with the use of nanotechnology for therapeutic purposes within your body knowing that a synthetic protein could be injected to abolish the nanoparticles in the case of an unexpected complication?

15. Would you be comfortable with the use of nanotechnology for therapeutic purposes, within your body, knowing that the nanoparticles could be bound with proteins so that they may be recognized and monitored while in the body?

16. If you were to use nanotechnology as a therapeutic method, would you be more comfortable using synthetic proteins or antibiotics/chemotherapeutics as a fail-safe for the procedure?

In today's world there are many instances in which fail-safes are applied in a programming sense. In nanotechnology, and more specifically nanobots, the need for a sound programming

architecture becomes much more apparent. In order to make nanobots more widely accepted the programmers have to be able to guarantee the safety of these devices.

17. Given the choice between pre-programmed and “remote” controlled nano-devices, which one would make you feel more comfortable, if they were to be injected into your body?

18. Given your current knowledge regarding computer programs, how comfortable would you be with having a nano-device injected into your body, programmed to provide treatment for a disease or to repair cells?

19. How comfortable would you be if a specialist were to be in the room controlling and guiding the nanobot throughout the reparation process?

20. As a consumer, how comfortable would you be to have to a medical procedure began or stopped by a computer program, for the purpose of saving your life?

Appendix B

WIKIPEDIA ARTICLE

The IQP team published the Wikipedia article titled Nanotechnology Fail-safes on November 16, 2008. The first issue the team encountered with this article involved the pictures. Wikipedia claimed that the pictures were not correctly sourced. The team fixed all sourcing issues on November 23. After that issue was corrected the team edited the main nanotechnology page on Wikipedia to include a link to the IQP team's page. No issues arose until December 14, where user Ukexpat deleted the IQP section of the page, and also claimed that the article contained "weasel words" which are words used in order to evade or retreat from a direct or forthright statement or position. User Gavia immer agreed on both issues. The team made an attempt to contact the users to ask if the section could be left up until the end of the project, and then be deleted. The users made no attempt to reply to the messages, and later deleted the entire page with no warning. The team re-uploaded the article, titling it Fail-safes in Nanotechnology. The article is still up currently. User Alan Liefting has edited some wording in the article to attempt to fix issues with tone and weasel words. Figure 13 below displays a full version of the Wikipedia article page.

Nanotechnology Fail-Safes

From Wikipedia, the free encyclopedia
(Redirected from User:NanoIQP/Nanotechnology Fail-Safes)

Nanotechnology is one of the most promising fields of research in the world today. One factor that prevents wide growth in the practical application of nanotechnology is social acceptance. There are currently theoretical and practical ways to implement fail-safe designs in nanotechnology. Development of these designs will reduce risks to users, and as a result, should increase the social acceptance of nanotechnology.

Wikipedia defines a fail-safe as: a device or feature which, in the event of failure, responds in a way that will cause no harm, or at least a minimum of harm, to other devices or personnel. Fail-safe principles are governed by national standards and engineering practices, and are widely used in conventional engineering design (see examples). It is possible to scale down current macro-scale fail-safe principles and devices for similar applications at the nano-scale.[1]

Perhaps the greatest challenge for the social acceptance of nanotechnology will arise when nanostructures start being injected into the human body, for the purpose of increasing health. While any structure would be developed to be bio-compatible and harmless, sound engineering design must take into account all possibilities of failure. Thus the design would include ways to manipulate them in the body in case failure occurs. Five health related research areas in which fail-safes or other preventative measures could be incorporated are discussed below.

Contents [hide] [hide]

Ferrous Nanoparticles [edit]

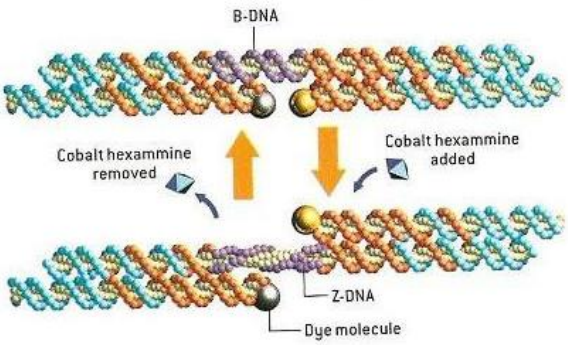
Many researchers are looking into creating nano-scale robots ("nanobots"), for the purpose of undertaking tasks where only robots on the nano scale can be used, such as inside the human body. These robots would have the ability to construct other nanostructures or perform medical procedures, and will be introduced into the body via an injection.[2] The robots' shells and circuits would be made of ferrous nanoparticles so that a magnetic field could be used to render them inactive, by preventing or manipulating their movement. In case of failure or malfunction, a small EMP or an MRI could be used to deactivate the nanobots, should they malfunction. Either technique induces a large electromagnetic field, corrupting the memory and shorting out the circuitry of any electronic device within range.

Amino Acids [edit]

Researchers are pursuing the building of nanostructures using amino acids. Nanostructures that are created using amino acids are constructed using only synthetic types of amino acids, which tags these structures with unique molecules. These engineered amino acids essentially form synthetic proteins that differ from the naturally occurring proteins in the human body. This difference in the engineered amino acids makes these proteins easy to isolate and target.[3] In case of failure or malfunction, it is possible to identify these proteins using the specifically targeted molecules, which act as a flag to indicate the location of the target. Then, another mechanism would be used to isolate them and deactivate their unwanted action. In essence, these engineered amino acids create a fail-safe mechanism that acts as an ON/OFF switch to protect the patient when a malfunction occurs.

DNA [edit]

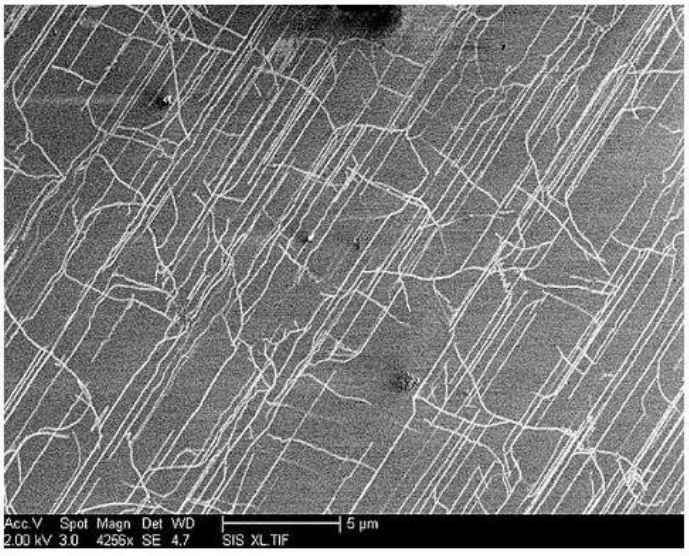
DNA within our bodies naturally breaks down, replicates itself, and rebuilds itself every time a cell divides. These processes are all controlled and completed by various enzymes. DNA molecules are composed of corresponding base pair nucleotides in a double helix formation which makes these processes very efficient, accurate, and predictable. Due to the ease in which DNA molecules can be fashioned, many publications in the academic society are geared towards creating nanostructures using DNA.[4] With a DNA-based nano-device, synthetic proteins could be created; designed for a specific purpose such as the extermination of the device. These synthetic proteins would be injected into the body to break down the DNA and render a nano-device harmless in the event of a malfunction.



Biological proteins within the human body perform three main functions: as structural building blocks, enzymes, and in cellular signaling. Synthetic proteins could be developed as a form of indicator and attached to a DNA-based nano-device.[5] This indicator would then be used for the purpose of monitoring nano-devices in the human body. If all DNA-based nano-devices were closely monitored in the human body, then those devices could be carefully watched, and eliminated or removed quickly in the event of a malfunction.

Programming [edit]

In today's world there are many instances in which fail-safes are applied in a programming sense. For example, street lights are programmed to set all lights to red when conflicting green lights are sensed. In nanotechnology, and more specifically nanobots, the need for a sound programming architecture becomes much more important due to potentially higher risks. A two-layer approach can be used to control nano-devices, first by providing a preprogrammed fail-safe functionality in case of anticipated failures, and secondly a remote controlled ability to override the programming in more complex situations.[6] The "remote" controlled nano-device would require a specialist in the room, to guide the nanobot throughout the procedure.



Cellular Engineering [edit]

Many researchers are developing methods that use bacteria to deliver drugs.[7] These bacteria can be "programmed" to perform a specific task, and can be directed to go to targeted locations in the body.[8] However, the bacteria may damage healthy organs or fail to deliver the medicine to the sick organ in the case of a malfunction. In such cases a fail-safe mechanism is required to neutralize the bacteria and prevent damage. In these cases an antibiotic is suitable as the fail-safe agent.

Interactive Qualifying Project [edit]

This article is part of an Interactive Qualifying Project (IQP) completed by a group of students from Worcester Polytechnic Institute. This project looks into possible fail-safes to be used in order to gain social acceptance of nanotechnology. Included is a survey that will examine how individuals from different backgrounds feel about the development of nanotechnology, and how implementing fail-safes may affect their opinions. It would improve the quality of our results if a few minutes were spent completing this survey . This survey is anonymous, and if completed the user may choose to be entered into a drawing for a free t-shirt from the WPI on-campus store.

Additional Images [edit]

Nanoelectromechanical Resonator

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External Links [edit]

Worcester Polytechnic Institute Nanotechnology Fail-Safes Survey

Figure 13 – Nanotechnology Fail-Safes Wikipedia article as published online.

Appendix C

IQP SURVEY QUESTIONS

Nanotechnology involves the use of particles only a few nanometers in size, that can be made from many materials such as metals or carbon. There are possible ways to prevent these particles from getting into the body unintentionally. There are also ways to manipulate them in the body if necessary.

1. How knowledgeable do you consider yourself to be regarding nanotechnology?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Very little knowledge, 5 = Extremely knowledgeable)
   Average

2. Were you aware that nanotechnology is already used in some consumer products?

   ☐ Yes ☐ No

3. How confident would you be breathing air in a building producing nanoparticles, if there were prevention methods in place to stop the diffusion of these particles throughout the air?

   1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Not confident, 5 = Very confident)
   Indifferent

4. If there were a medical procedure to save your life that involved injecting ferrous nanoparticles into your body, would you be confident with the procedure knowing that a magnetic field could be used to disable the particles?

   ☐ Yes ☐ No ☐ Undecided

5. Would you be more confident with the development of nanotechnology, if there were automated sensors to detect and warn you of harmful levels of nanoparticles in your surroundings?

   ☐ Yes ☐ No ☐ Undecided

Today's research in nanotechnology includes: amino acids, DNA, programming, and molecular engineering. All of these methods are made so that they are bio-compatible and are harmless to the human body.

6. Nano-structures using man-made **amino acids** could be introduced into the human body. These structures can be tagged to specific molecules, enabling the capability of an on/off switch, in essence, a fail-safe feature to protect the user. How confident would you be to have such a device circulating in your body?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Not confident, 5 = Very confident)
Indifferent

7. Nano-structures using **DNA** could be introduced into the human body. These structures may be taken apart using proteins enabling the capability of an on/off switch. How confident would you be to have such a device circulating in your body?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Not confident, 5 = Very confident)
Indifferent

8. Would you be confident having to take a pill to begin or stop a medical procedure, for the purpose of saving your life?

☐ Yes ☐ No ☐ Undecided

9. Would you be confident having an injection to begin or stop a medical procedure, for the purpose of saving your life?

☐ Yes ☐ No ☐ Undecided

10. Would you be wiling to have a nano-medical device made of bio-compatible material circulating in your body, knowing that there is a safe method to remove the device?

☐ Yes ☐ No ☐ Undecided

Antibiotics have been used for nearly 100 years as a chemotherapeutic agent, chemicals with which to kill microorganisms in the human body such as bacteria or fungi. Antibiotics or similar chemotherapeutic methods could also be used for the control or abolition of nanoparticles in the body.

11. How accepting would you be of the use of a new antibiotic medicine developed for use with nanotechnology?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Very unaccepting, 5 = Extremely accepting)
Average

12. Would you be confident with the use of nanotechnology for therapeutic purposes, knowing that a chemotherapeutic fail-safe is available in the case of an unexpected complication?

☐ Yes ☐ No ☐ Undecided

Biological proteins within the human body perform three main functions: as structural building blocks, enzymes, and cellular signaling. Synthetic proteins could be used as enzymes or biological signalers for the purpose of monitoring or breaking down nanoparticles in the human body.

13. How accepting would you be of the use of synthetic proteins in your body for medical purposes?

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Very unaccepting, 5 = Extremely accepting)
Average

14. Would you be confident with the use of nanotechnology for therapeutic purposes within your body, knowing that a synthetic protein could be injected to disable the nanoparticles in the case of an unexpected complication?

☐ Yes ☐ No ☐ Undecided

15. Would you be confident with the use of nanotechnology for therapeutic purposes, knowing that the nanoparticles could be bound with proteins so that they may be recognized and monitored while in the body?

☐ Yes ☐ No ☐ Undecided

In today's world there are many instances in which fail-safes are applied in a programming sense. In nanotechnology, and more specifically nanobots (microscopic robots used in nanotechnology), the need for a sound programming architecture becomes more important. In order to make nanobots more widely accepted the programmers have to be able to guarantee the safety of these devices.

16. Would you be more confident with "remote" controlled nano-devices rather than pre-programmed nano-devices, if they were to be injected into your body?

    ☐ Yes ☐ No ☐ Undecided

17. How confident would you be with having a nano-device injected into your body that was programmed to provide treatment for a disease or to repair cells?

    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Very uncomfortable, 5 = Extremely comfortable)
    Indifferent

18. Would you be confident having a specialist in the room controlling and guiding the nanobot throughout a medical procedure?

    ☐ Yes ☐ No ☐ Undecided

19. Would you be confident having a medical procedure started or stopped by a computer program, for the purpose of saving your life?

    ☐ Yes ☐ No ☐ Undecided

20. If nano-sized circuits could be introduced into the human body they could be programmed to do specific tasks, as well as be directed to be turned on or off. How confident would you be to have such a device circulating in your body?

    1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ (1 = Not confident, 5 = Very confident)
    Indifferent

Appendix D

This appendix analyzes the data collected in more detail than previously in the Results and Analysis section. The data is separated into the four target populations: WPI students, WPI professors, Moola users, and Wikipedia users. Each population is then broken down into six sections which are: overall mean, mean of the people who answered one on question one, mean of the people who answered two on question one, mean of the people who answered three on question one, mean of the people who answered four on question one, and the mean of the people who answered five on question one. Error bars have been placed only on graphs which are the overall mean of the category. The reason for this is that some of the individual sections had so few participants that applying error bars to sections other than the mean of the category would be of little significance.

Student Mean

The overall trend that can be seen in Figure 14 for most students is that they are not very knowledgeable about nanotechnology, which shows that even though they are in a technology oriented environment, they do not get a lot of exposure to this type of technology. However, these students were moderately confident with breathing air in a building producing nanoparticles, and slightly comfortable with nano-structures using man-made amino acids. Most students were somewhat comfortable with nano-structures using DNA, and more confident with a "remote" controlled nano-devices rather than a pre-programmed. The students were also reasonably comfortable with nano-sized circuits that would be programmed to do specific tasks, as well as be directed to be turned on or off.

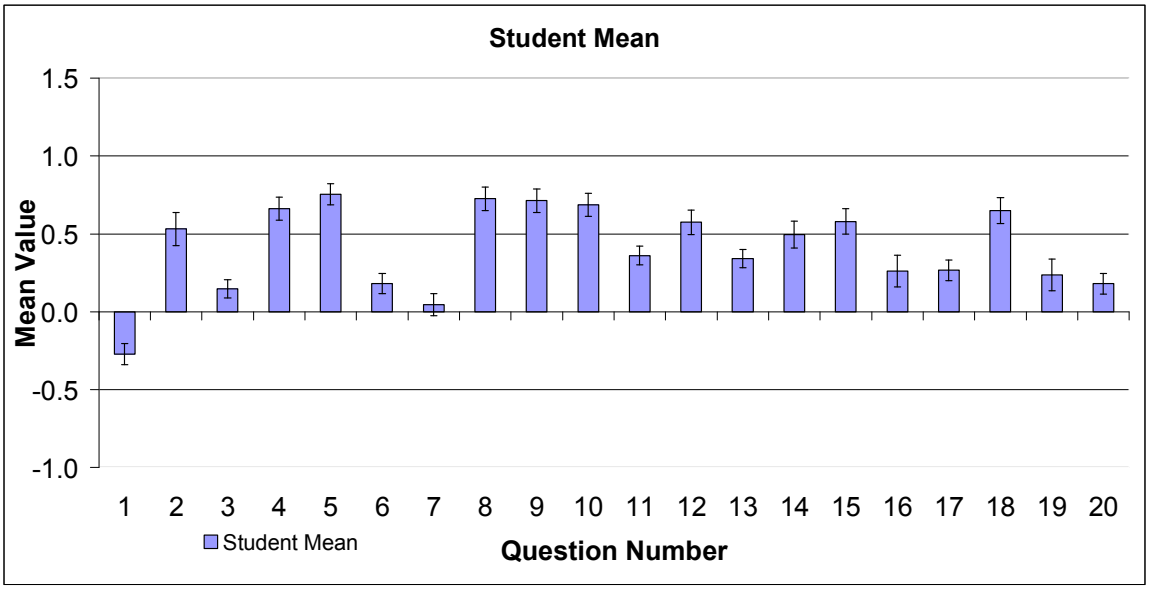

Figure 14 – Overall mean social acceptance of WPI students by question including error bars.

Student Mean – Answered 1 on Question # 1

Students who answered 1 on question one are students who consider themselves not knowledgeable about nanotechnology at all. These students' comfort level with the technology can be seen, in Figure 15. Most of the students in this category were vaguely confident with breathing air containing nanoparticles as well as with nano-structures amino acids circulating in their body. Another trend which was seen with these students was that they moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed. However, the students were not comfortable with DNA nano-structures even though they were comfortable with the usage of proteins in their body.

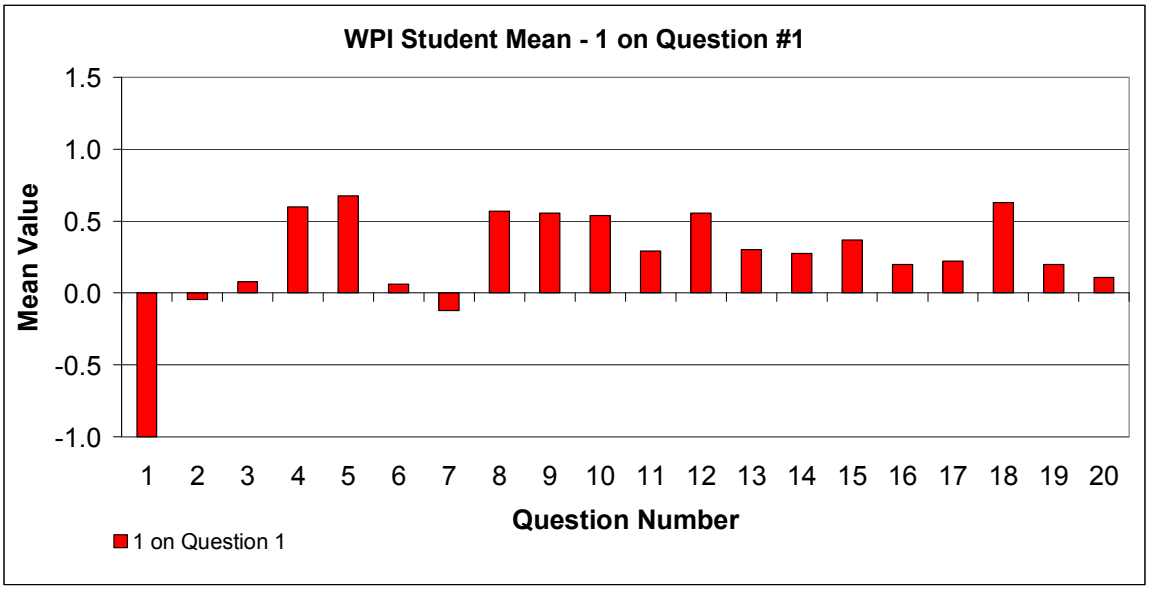

Figure 15 – Social Acceptance of least self-proclaimed knowledge WPI student results by question.

Student Mean – Answered 2 on Question # 1

Students who answered 2 on question one are students who consider themselves to have little knowledge about nanotechnology. These students' comfort level with the technology can be seen, in Figure 16. Most of the students in this category were indifferent with breathing air containing nanoparticles as well as having a nano-device made of DNA or amino acids injected into their body. Another trend which was seen with these students was that they were moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed. Also, the students in this group were very comfortable about having a specialist in the room controlling and guiding the nano device but indifferent about having nano-sized circuits that would be programmed to do specific tasks.

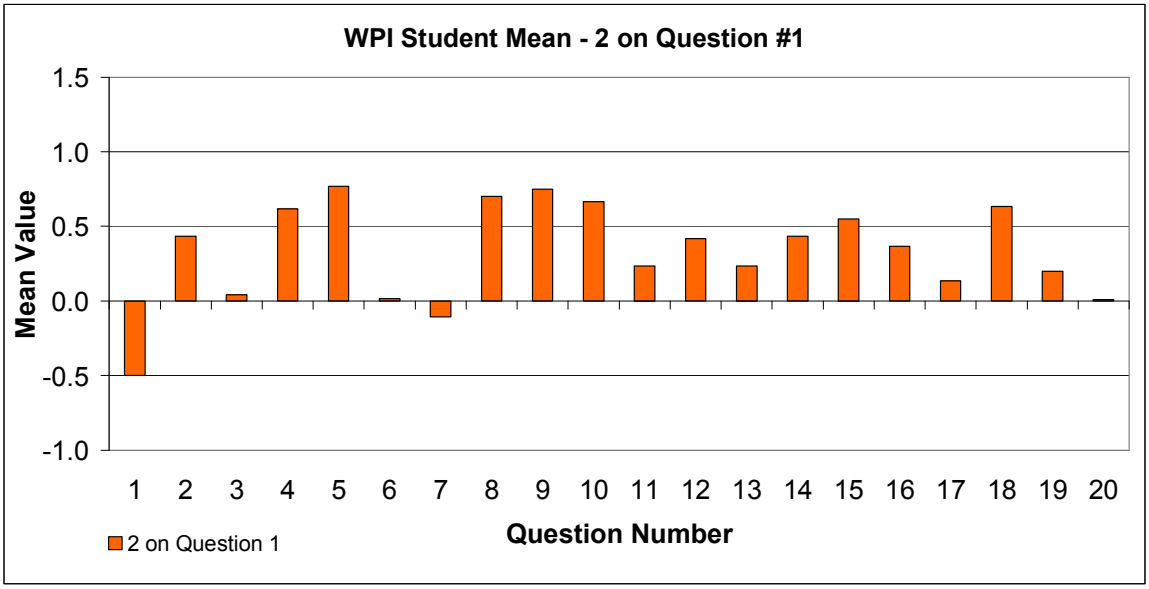

Figure 16 - Social Acceptance of lower self-proclaimed knowledge WPI student results by question.

Student Mean – Answered 3 on Question #1

Students who answered 3 on question one are students who consider themselves to have an average knowledge in the field of nanotechnology. These student's comfort level with the technology can be seen, in Figure 17. These students were very comfortable with having ferrous nanoparticle injected into the body and were confident with the concept of automated sensors to detect harmful levels of nanoparticles. These students were also accepting of nanotechnology incorporated in traditional medical procedures. Overall these students were fairly confident in all aspects of nanotechnology referred to in the survey, however, DNA and amino acid based nanotechnology as well as programming in nanotechnology received less support.

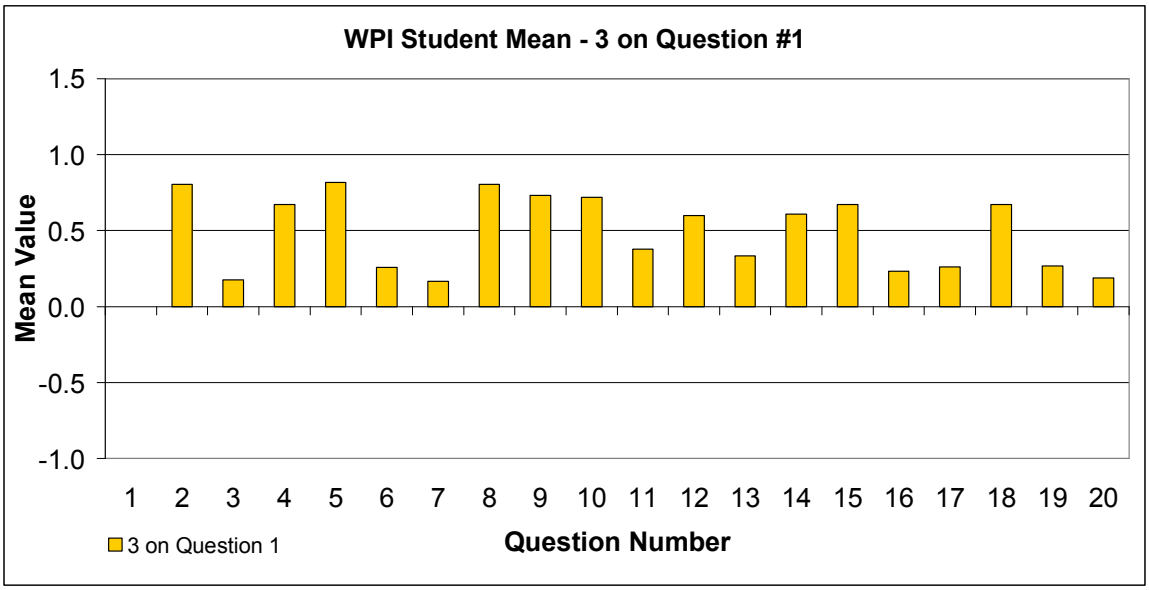

Figure 17 - Social Acceptance of average self-proclaimed knowledge WPI student results by question.

Student Mean – Answered 4 on Question # 1

Students who answered 4 on question one are students who consider themselves fairly knowledgeable in the field of nanotechnology. These students' comfort level with the technology can be seen, in Figure 18. Most of the students in this category were fairly confident with breathing air containing nanoparticles as well as with nano-structures amino acids circulating in their body. Also, the students in this group were indifferent about having a specialist in the room controlling and guiding the nano-device as well as about having nano-sized circuits that would be programmed to do specific tasks. Another trend which was seen with these students was that they are moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed.

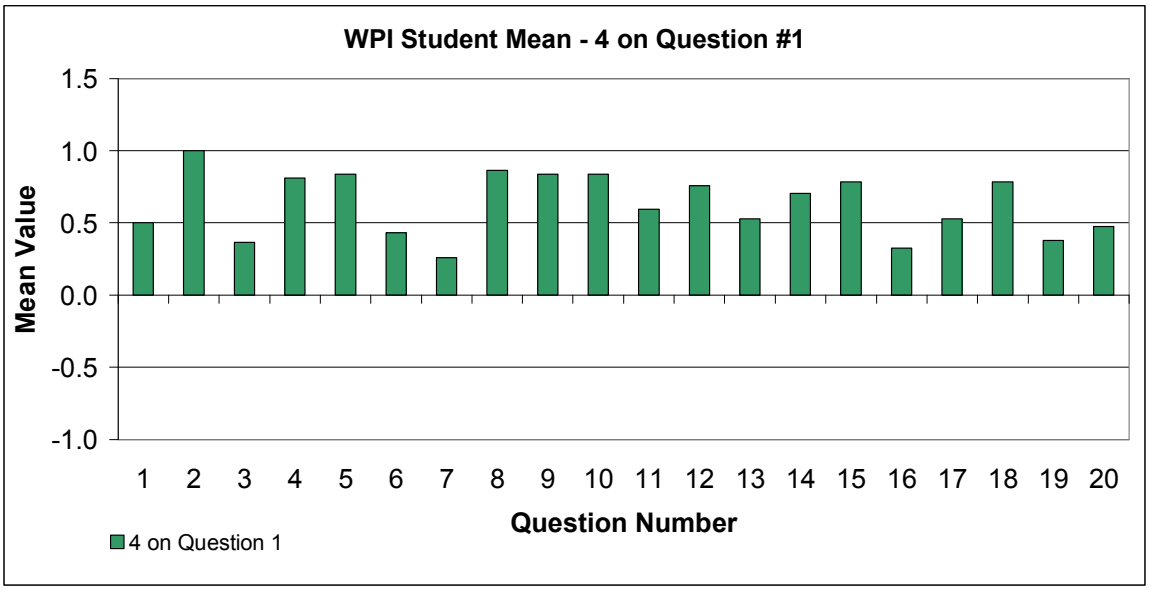

Figure 18 - Social Acceptance of higher self-proclaimed knowledge WPI student results by question.

Student Mean – Answered 5 on Question # 1

Students who answered 5 on question one are students who consider themselves very knowledgeable in the field of nanotechnology. These students' comfort level with the technology can be seen, in Figure 19. Most of the students in this category were only slightly confident with breathing air containing nanoparticles and not confident with having a medical procedure started or stopped by a computer program. Also, these students were only faintly supportive of having a specialist in the room controlling and guiding the nanobot throughout a medical procedure. On the other hand, this group of students was very confident with using nanotechnology in traditional medial techniques and the concept of bio-compatible materials being used for nanotechnology.

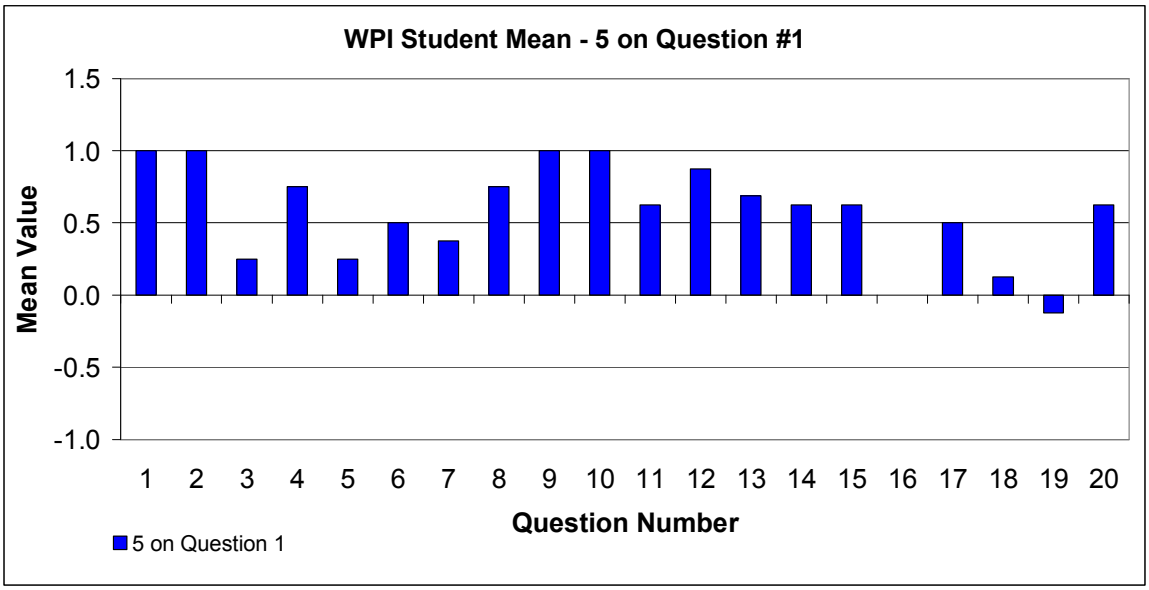

Figure 19 - Social Acceptance of highest self-proclaimed knowledge WPI student results by question.

Professor Mean

The overall trend that can be seen in Figure 20 for most WPI professors is that they are not very knowledgeable about nanotechnology, which shows that even though they are most likely educated in technology based fields, they do not receive a lot of exposure to this type of technology. The professors were nearly indifferent about breathing air in a building producing nanoparticles, as well as with nano-structures using man-made amino acids. Most professors were uncomfortable with nano-structures using DNA, but indifferent regarding a "remote" controlled nano-devices rather than a pre-programmed. Also, the professors were reasonably comfortable with nano-sized circuits that would be programmed to do specific tasks, as well as be directed to be turned on or off.

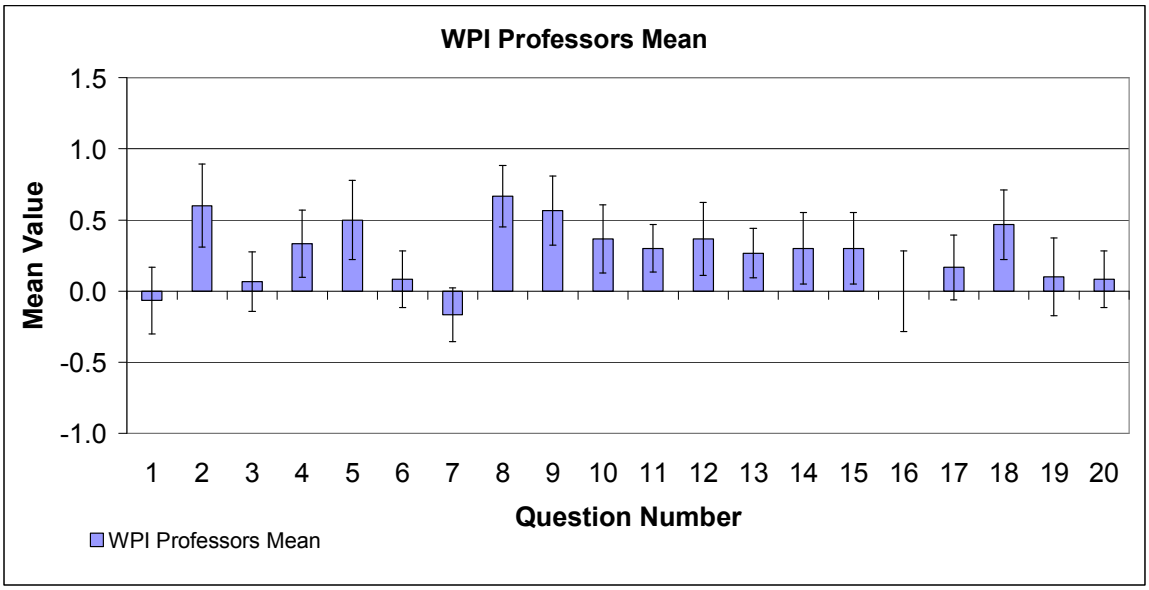

Figure 20 - Overall mean social acceptance of WPI professors by question including error bars.

Professor Mean – Answered 1 on Question # 1

Professors who answered 1 on question one are professors who consider themselves as not knowledgeable about nanotechnology at all. These professors' comfort level with the technology can be seen in Figure 21. Most of the professors in this category were not confident with breathing air containing nanoparticles and indifferent about nano-structures amino acids circulating in their body. Another trend which was seen with these professors was that they moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed. However, the professors were not comfortable with DNA nano-structures even though they were comfortable with the usage of proteins in their body.

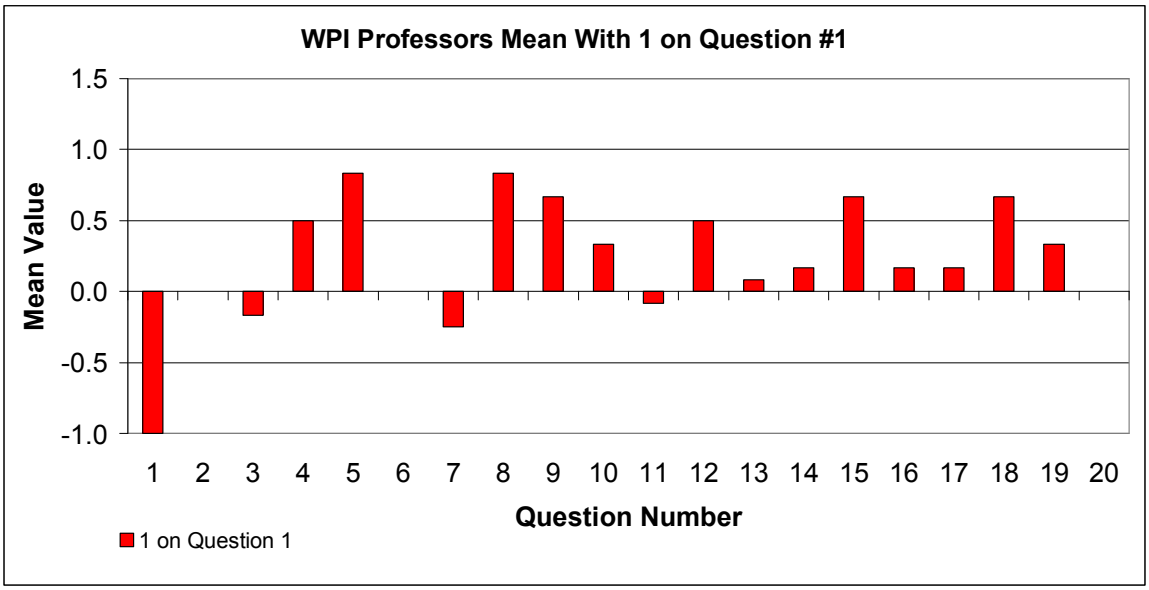

Figure 21 - Social Acceptance of least self-proclaimed knowledge WPI professor results by question.

Professor Mean – Answered 2 on Question # 1

Professors who answered 2 on question one are professors who consider themselves to have little knowledge about nanotechnology. These professors' comfort level with the technology can be seen in Figure 22. Most of the professors in this category were not confident with breathing air containing nanoparticles and indifferent anout having a nano-device injected into their body. Another trend which was seen with these professors was that they moderately more confident with a pre-programmed nano-devices rather than a "remote" controlled one. Also, the professors in this group were fairly confident about having a specialist in the room controlling and guiding the nano device as well as about having a nano-sized circuit that would be programmed to do specific tasks. However, the professors were not comfortable with DNA nano-structures as well as indifferent to nano-structures made of amino acids.

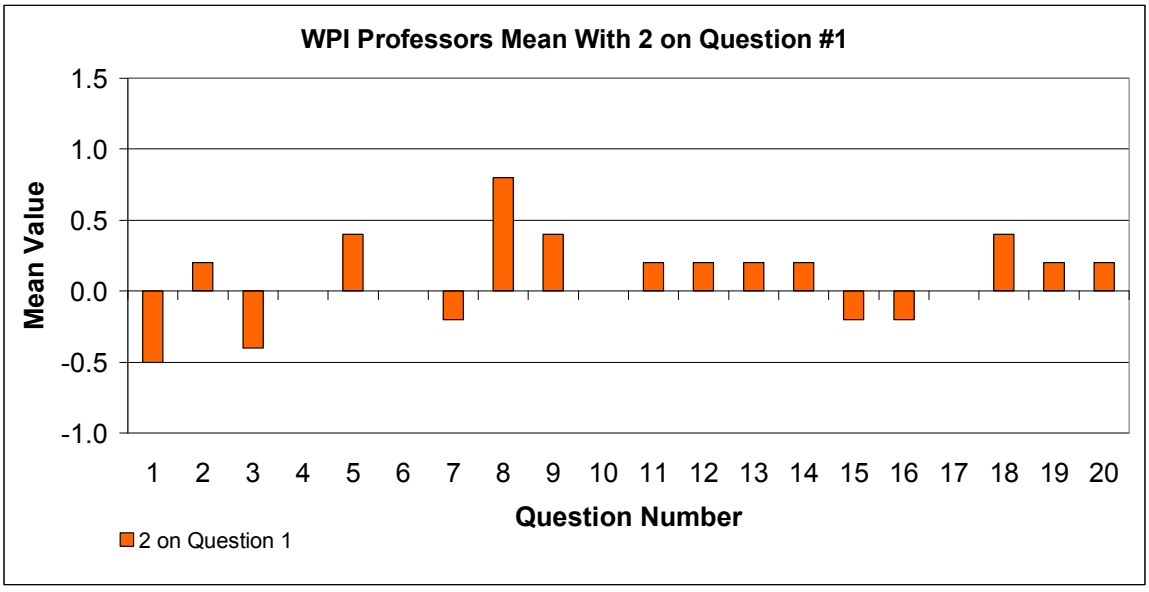

Figure 22 - Social Acceptance of lower self-proclaimed knowledge WPI professor results by question.

Professor Mean – Answered 3 on Question # 1

Professors who answered 3 on question one are professors who consider themselves to have average knowledge in the field of nanotechnology. These professors' comfort level with the technology can be seen in Figure 23. The professors in this group were fairly accepting of most aspects on nanotechnology included in the survey. They were indifferent about whether a nano-device injected into the body should be "remote" controlled or pre-programmed. The two areas of nanotechnology that were not accepted were nano-structures made of DNA, and a mdecial procedure started or stopped by a computer program.

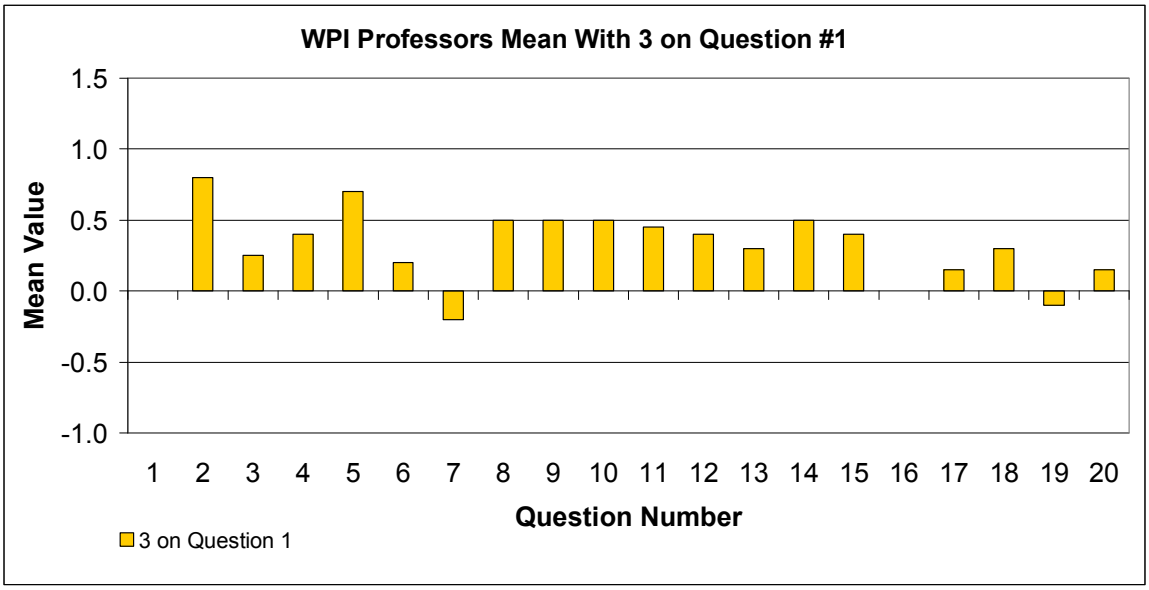

Figure 23 - Social Acceptance of average self-proclaimed knowledge WPI professor results by question.

Professor Mean – Answered 4 on Question # 1

Professors who answered 4 on question one are professors who consider themselves quite knowledgeable in the field of nanotechnology. These professors' comfort level with the technology can be seen in Figure 24. Most of the professors in this category were slightly confident with breathing air containing nanoparticles as well as with ferrous nanoparticles circulating in their body. Also, the professors in this group were slightly comfortable with having a specialist in the room controlling and guiding the nano device but not comfortable with having a nano-sized circuit that would be programmed to do specific tasks. Another trend which was seen with these professors was that they were indfifferent about a "remote" controlled nano-devices rather than a pre-programmed.

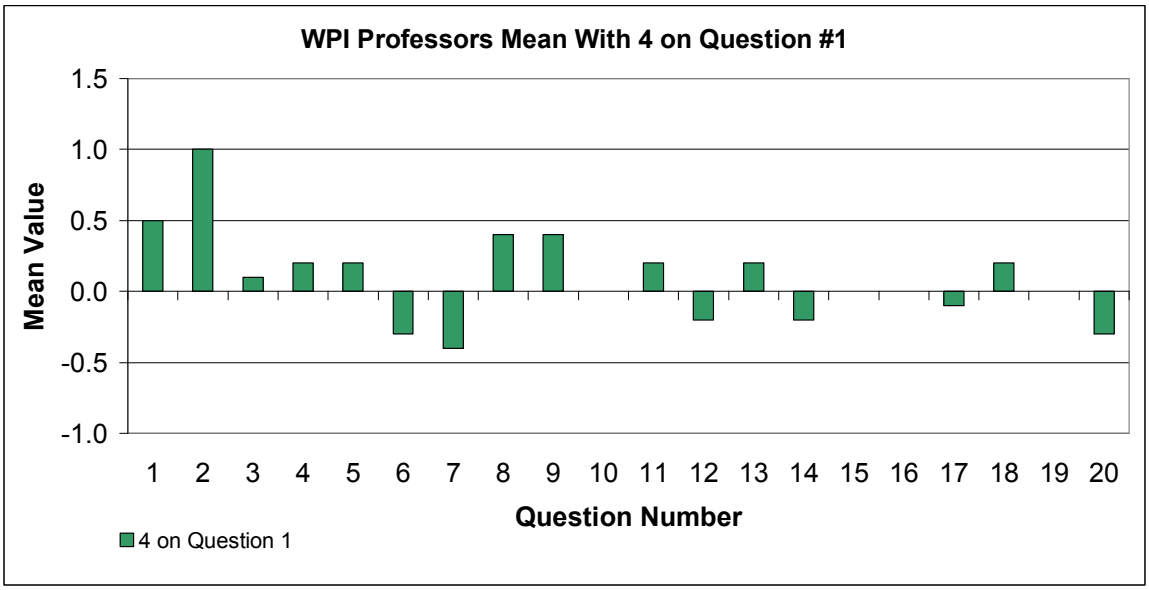

Figure 24 - Social Acceptance of higher self-proclaimed knowledge WPI professor results by question.

Professor Mean – Answered 5 on Question # 1

Professors who answered 5 on question one are professors who consider themselves very knowledgeable in the field of nanotechnology. These professors' comfort level with the technology can be seen in Figure 25. Most of the professors in this category were somewhat confident with breathing air containing nanoparticles as well as with having a medical procedure started or stopped by a computer program. Also, these professors were extremely confident having a specialist in the room controlling and guiding the nanobot throughout a medical procedure. Every question was answered with positive results, with the exception of questions 5 and 16 which had values of zero. This means they felt indifferent about "remote controlled" nano-devices versus pre-programmed ones, as well as about automated sensors for nanotechnology.

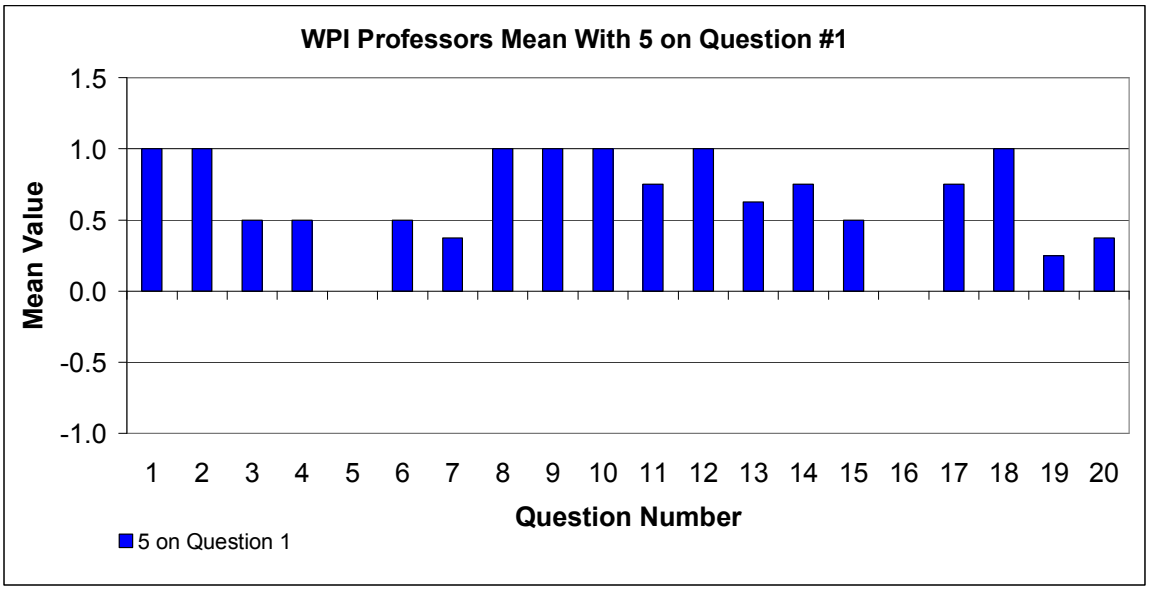

Figure 25 - Social Acceptance of highest self-proclaimed knowledge WPI professor results by question.

Moola Mean

The overall trend that can be seen in Figure 26 by most forum users is that they are not very knowledgeable about nanotechnology. However, forum users were slightly confident with breathing air in a building producing nanoparticles, as well as with nano-structures using man-made amino acids. Most forum users were indifferent about nano-structures using DNA, but more confident with a "remote" controlled nano-devices rather than a pre-programmed. Also, the forum users were mildly comfortable with nano-sized circuits that would be programmed to do specific tasks, as well as be directed to be turned on or off. The Moola users were very comfortable with using nanotechnology in traditional medical techniques as well as injecting nanoparticles or devices into the body.

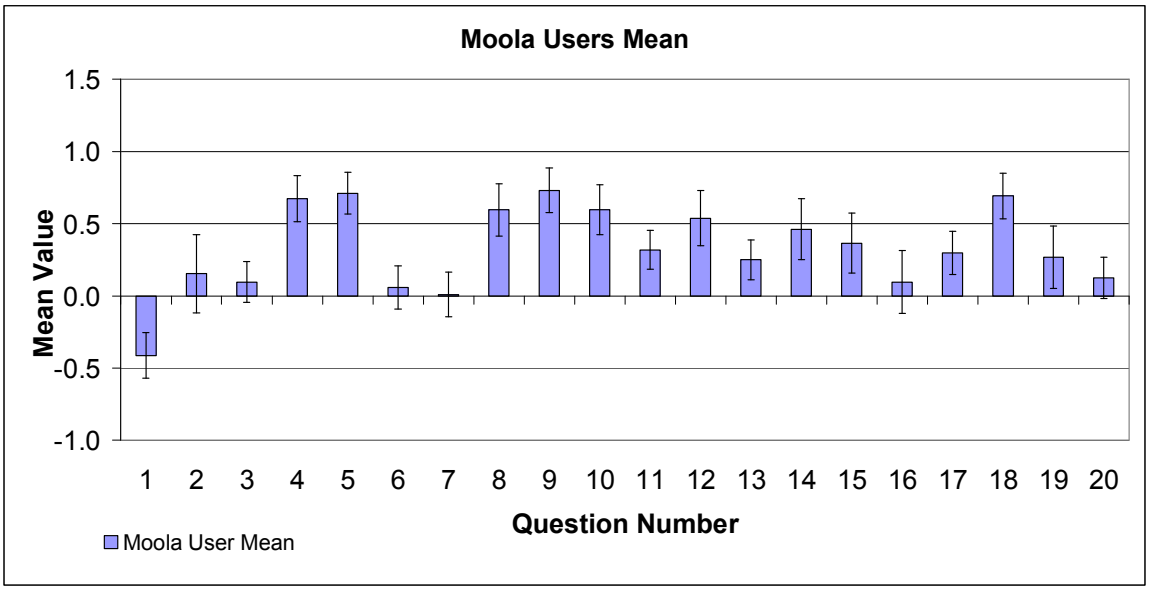

Figure 26 - Overall mean social acceptance of Moola users by question including error bars.

Moola Mean – Answered 1 on Question # 1

Forum users who answered 1 on question one are forum users who consider themselves to have no knowledge about nanotechnology. These forum users' comfort level with the technology can be seen in Figure 27. Most of the forum users in this category were somewhat uncomfortable with breathing air containing nanoparticles and and with nano-structures amino acids circulating in their body. Another trend which was seen with these forum users was that they moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed. The forum users were also slightly comfortable with DNA nano-structures even though they were comfortable with the usage of proteins in their body.

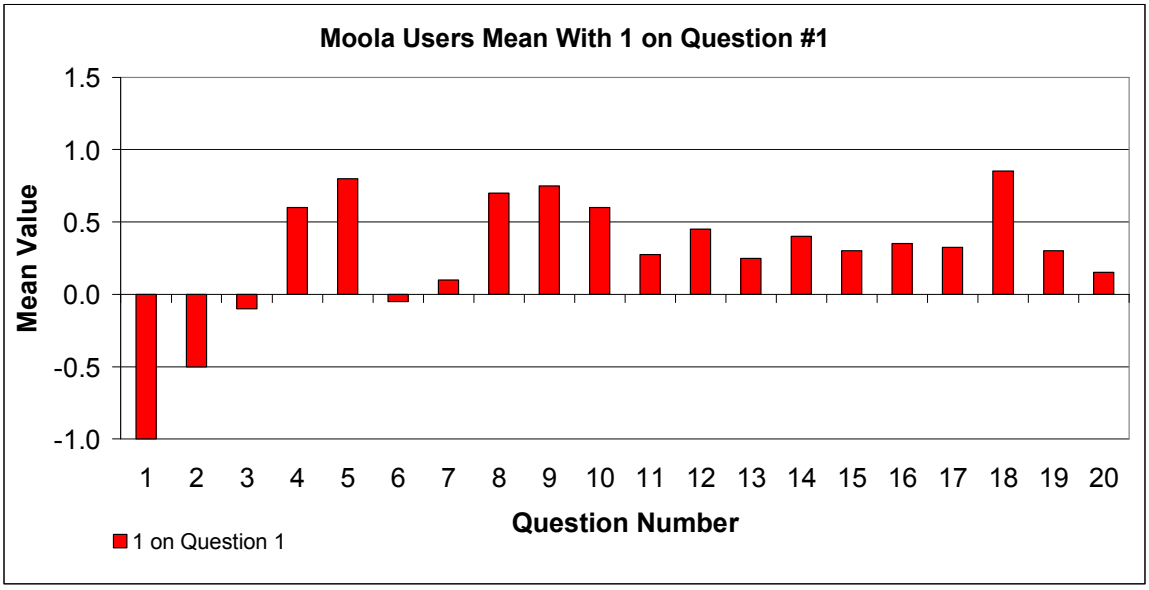

Figure 27 - Social Acceptance of least self-proclaimed knowledge Moola user results by question.

Moola Mean – Answered 2 on Question # 1

Forum users who answered 2 on question one are forum users who consider themselves to have little knowledge about nanotechnology. These forum users' comfort level with the technology can be seen in Figure 28. Most of the forum users in this category were somewhat confident with breathing air containing nanoparticles and even more confident with having a nano-device injected into their body. Another trend which was seen with these forum users was that they are moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed one. Also, the forum users in this group are accepting of having a specialist in the room controlling and guiding the nano device, but indifferent regarding nano-sized circuits that would be programmed to do specific tasks. The forum users were not comfortable with DNA nano-structures, but slightly comfortable with nano-structures made of amino acids.

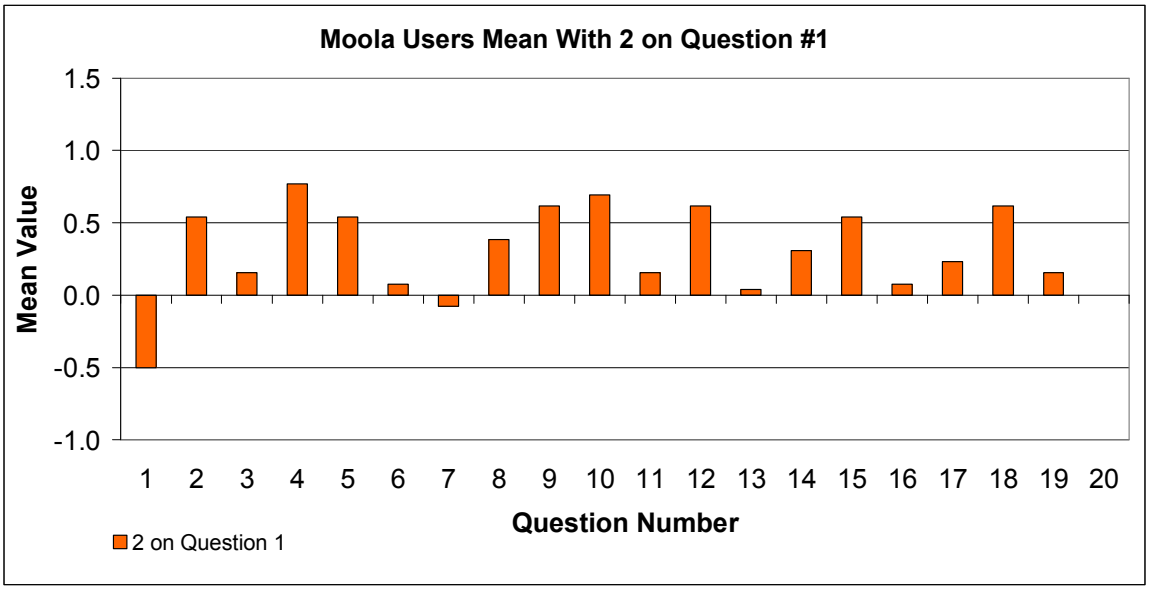

Figure 28 - Social Acceptance of lower self-proclaimed knowledge Moola user results by question.

Moola Mean – Answered 3 on Question # 1

Forum users who answered 3 on question one are forum users who consider themselves to have average knowledge in the field of nanotechnology. These forum users' comfort level with the technology can be seen in Figure 29. A trend that can be seen with these users is that they are accepting of breathing air in a building producing nano-particles, as well as very accepting of a medical procedure using ferrous nanoparticles. Also, these users were accepting of a possible antibiotic medicine for use with nanotechnology as well as using synthetic proteins as a fail-safe for disabling nano-structures. However, they were not accepting of a medical procedure that would be started or stopped by a computer program.

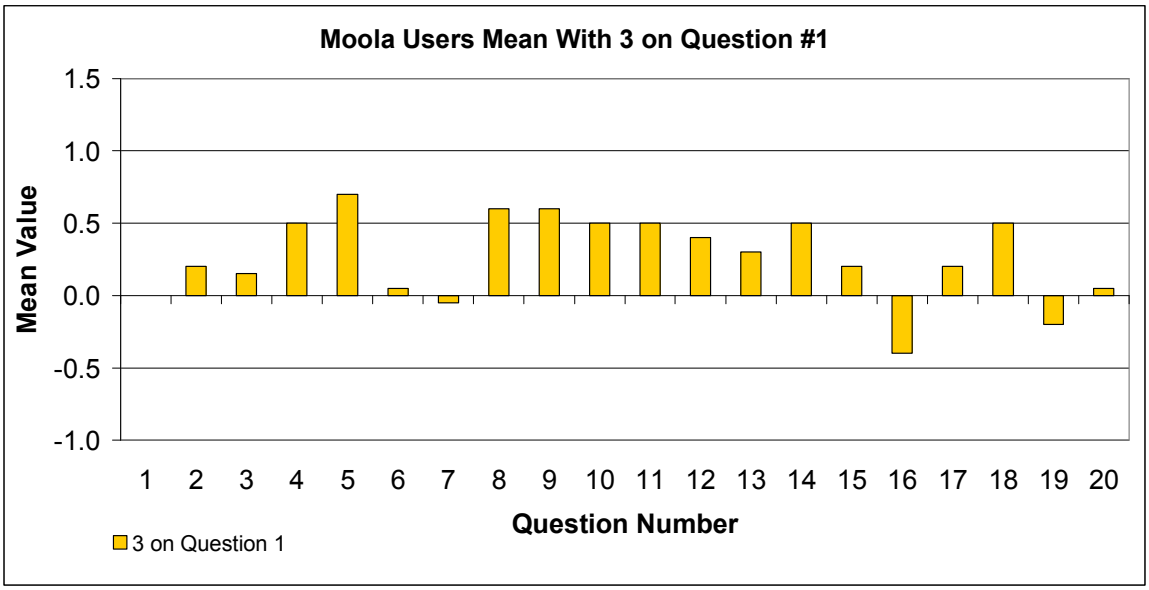

Figure 29 - Social Acceptance of average self-proclaimed knowledge Moola user results by question.

Moola Mean – Answered 4 on Question # 1

Forum users who answered 4 on question one are forum users who consider themselves fairly knowledgeable in the field of nanotechnology. These forum users' comfort level with the technology can be seen in Figure 30. Most of the forum users in this category were fairly confident with breathing air containing nanoparticles as well as with nano-structures amino acids circulating in their body. Also, the forum users in this group were comfortable having a specialist in the room controlling and guiding the nano device as well as having nano-sized circuits that would be programmed to do specific tasks. Another trend which was seen with these forum users was that they are moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed. These users were extremely confident in having a medical procedure started or stopped by a computer program.

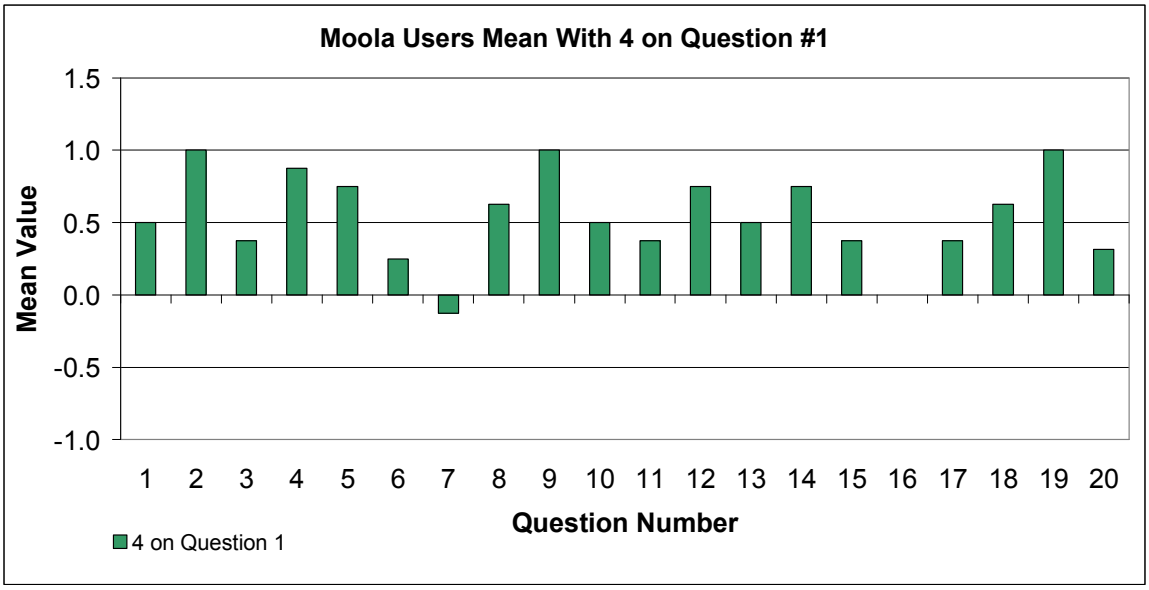

Figure 30 - Social Acceptance of higher self-proclaimed knowledge Moola user results by question.

Moola Mean – Answered 5 on Question # 1

Forum users who answered 5 on question one are forum users who consider themselves very knowledgeable in the field of nanotechnology. These forum users' comfort level with the technology can be seen in Figure 31. Most of the forum users in this category were somewhat confident with breathing air in a building containing nanoparticles, but were undecided about having a medical procedure started or stopped by a computer program. Also, these forum users were extremely confident having a specialist in the room controlling and guiding the nanobot throughout a medical procedure. The trend with these users is that they are accepting of all aspects of our survey other than having a medical procedure started or stopped by a computer program.

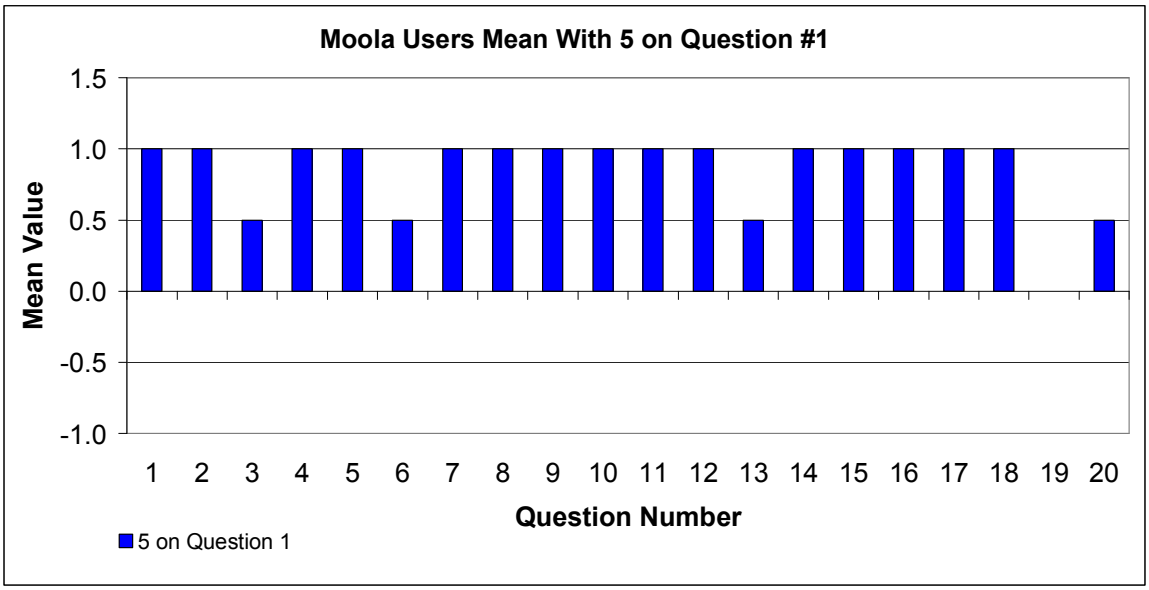

Figure 31 - Social Acceptance of highest self-proclaimed knowledge Moola user results by question.

Wikipedia Mean

The overall trend that can be seen in Figure 32 by most Wikipedia users is that they are not very knowledgeable about nanotechnology. Wikipedia users were only slightly confident with breathing air in a building producing nanoparticles, as well as with nano-structures made of DNA. Most Wikipedia users were somewhat comfortable with nano-structures using man-made amino acids, but significantly more confident with a "remote" controlled nano-devices rather than a pre-programmed. Also, the Wikipedia users were reasonably comfortable with nano-sized circuits that would be programmed to do specific tasks, as well as be directed to be turned on or off. All questions from this population received positive results with the exception of the first question regarding self-proclaimed knowledge.

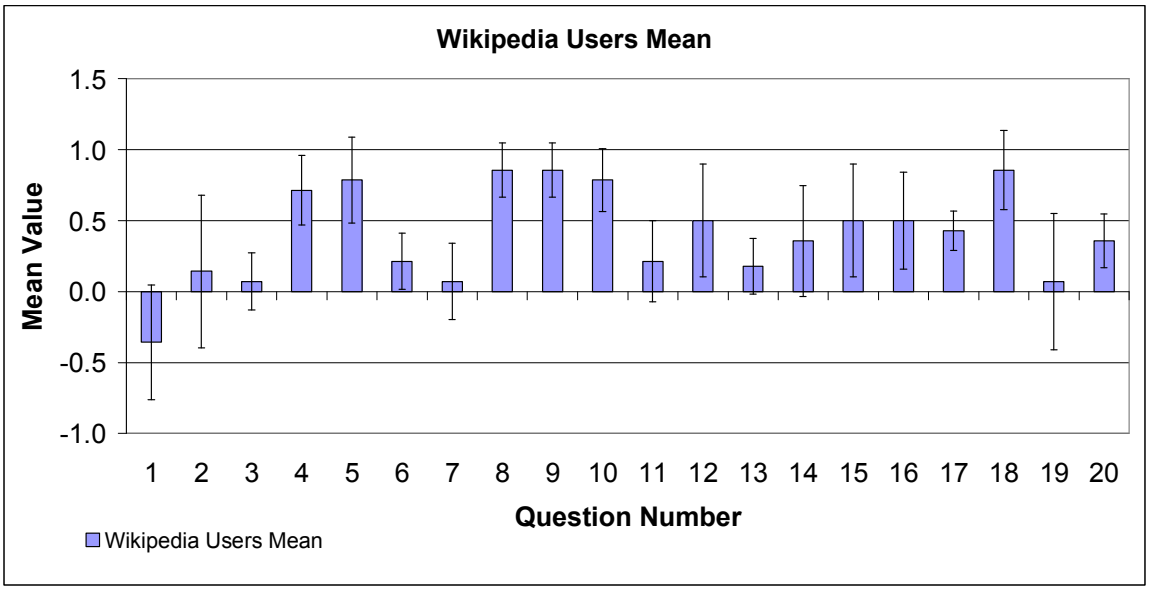

Figure 32 - Overall mean social acceptance of Wikipedia users by question including error bars.

Wikipedia Mean – Answered 1 on Question # 1

Wikipedia users who answered 1 on question one are users who consider themselves to be not knowledgeable about nanotechnology at all. These Wikipedia users' comfort level with the technology can be seen in Figure 33. Most of the Wikipedia users in this category were not confident with breathing air containing nanoparticles, but reasonably comfortable with nano-structures built with DNA circulating in their body. Another trend which was seen with these users was that they moderately more confident with a "remote" controlled nano-devices rather than a pre-programmed. Interestingly, the Wikipedia users were comfortable with ferrous nanoparticles as well as comfortable with the usage of antibiotics with nanotechnology.

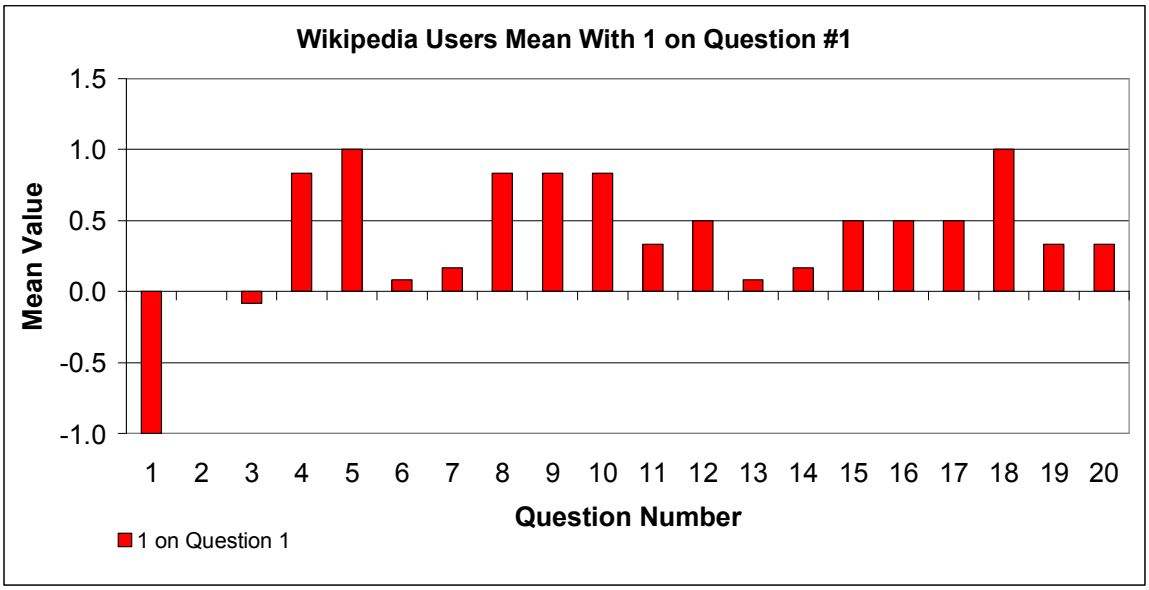

Figure 33 - Social Acceptance of least self-proclaimed knowledge Wikipedia user results by question.

Wikipedia Mean – Answered 2 on Question # 1

Wikipedia users who answered 2 on question one are users who consider themselves to have little knowledge about nanotechnology. These Wikipedia users' comfort level with the technology can be seen in Figure 34. The overall trend with these users is that they are somewhat accepting, although there are some areas where they are not. These unsupported areas are using a computer program to start or stop a medical procedure and the breathing of nanoparticles. Also they were more confident with "remote" controlled devices rather than pre-programmed ones. Areas where they were particularly accepting were having a specialist in the room guiding the nanostructures through a procedure, as well as having nano circuits in the body to carry out specific tasks.

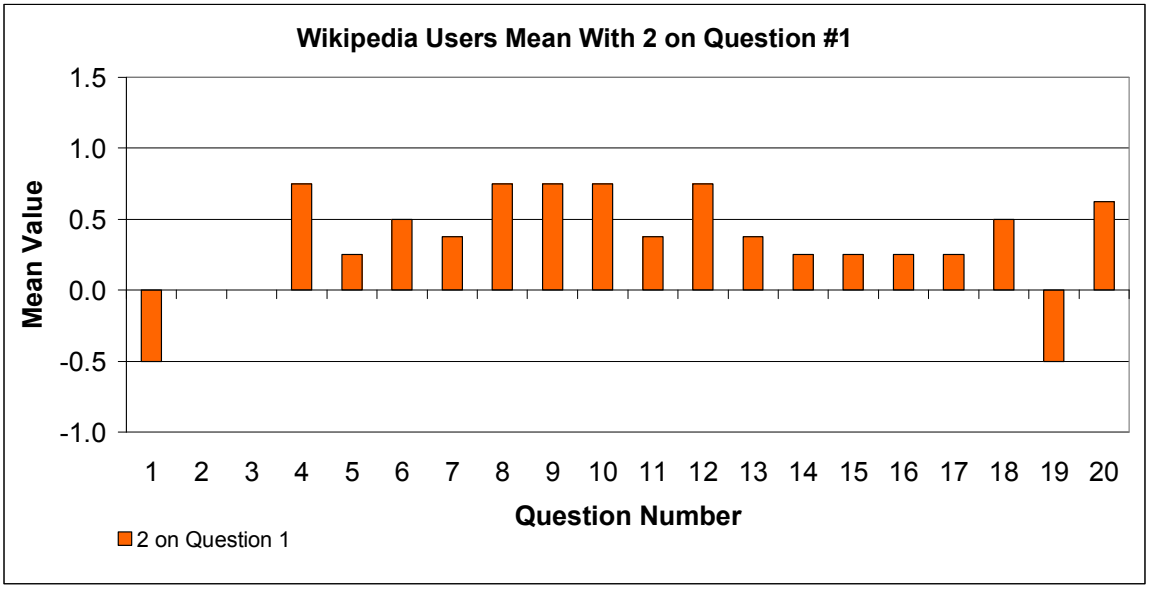

Figure 34 - Social Acceptance of lower self-proclaimed knowledge Wikipedia user results by question.

Wikipedia Mean – Answered 3 on Question # 1

There were no Wikipedia users who selected a 3 for their level of self-proclaimed knowledge regarding nanotechnology.

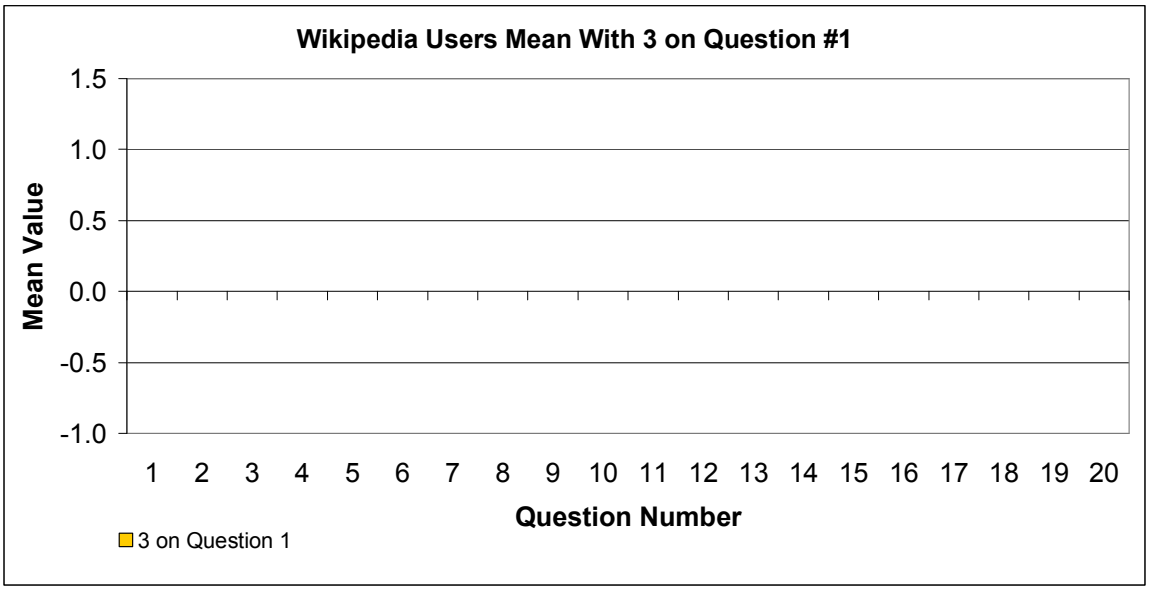

Figure 35 - Social Acceptance of average self-proclaimed knowledge Wikipedia user results by question.

Wikipedia Mean – Answered 4 on Question # 1

Wikipedia users who answered 4 on question one are users who consider themselves to be knowledgeable about nanotechnology. These Wikipedia users' comfort level with the technology can be seen in Figure 36. The results for this population show a general trend of acceptance, with a few interesting areas. These include a high increase in acceptance if there were sensors to detect dangerous levels of nano-particles in the air, as well as a higher acceptance of "remote" controlled nanodevices rather than pre-programmed ones. The only area that had a negative acceptance was related to the use of DNA nanostructures in the human body.

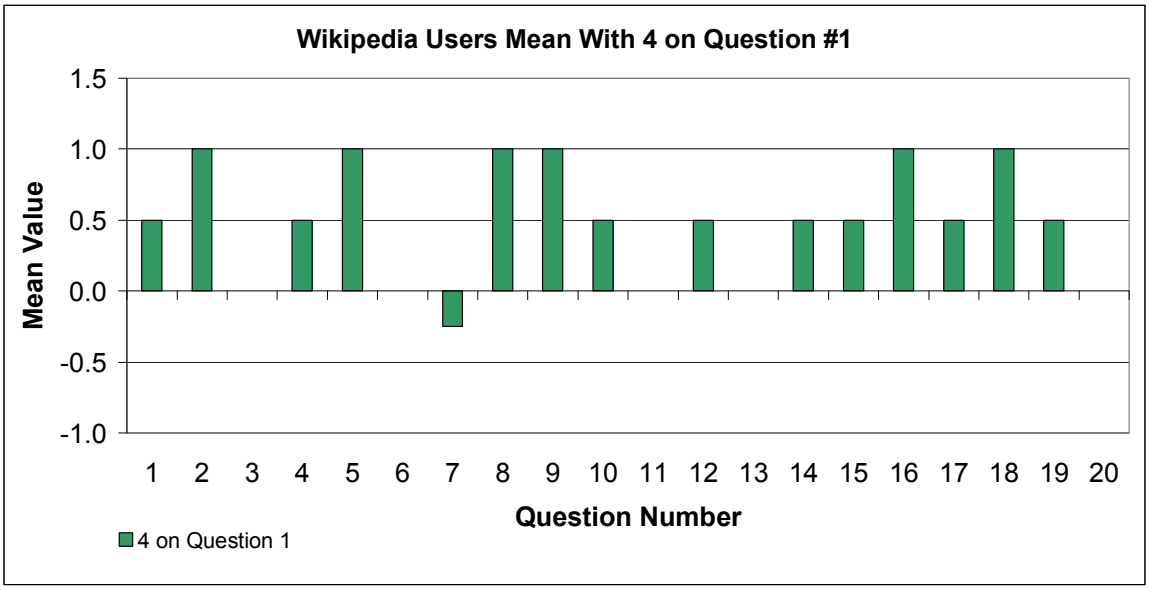

Figure 36 - Social Acceptance of higher self-proclaimed knowledge Wikipedia user results by question.

Wikipedia Mean – Answered 5 on Question # 1

Wikipedia users who answered 5 on question one are users who consider themselves to be very knowledgeable about nanotechnology. These Wikipedia users' comfort level with the technology can be seen in Figure 37. This chart shows a general psoitive acceptance, with the exception of the use of DNA based nano-structures and antibiotics for use with nanotechnology. These users showed a higher level of acceptance of breathing in air in a building producing nanostructures than in most other populations. These users were also very accepting of having nano-structures made of bio-compatible materials, the use of synthetic protein based nanoparticles, and having a specialist controlling and guiding nanobots for a medical procedure.

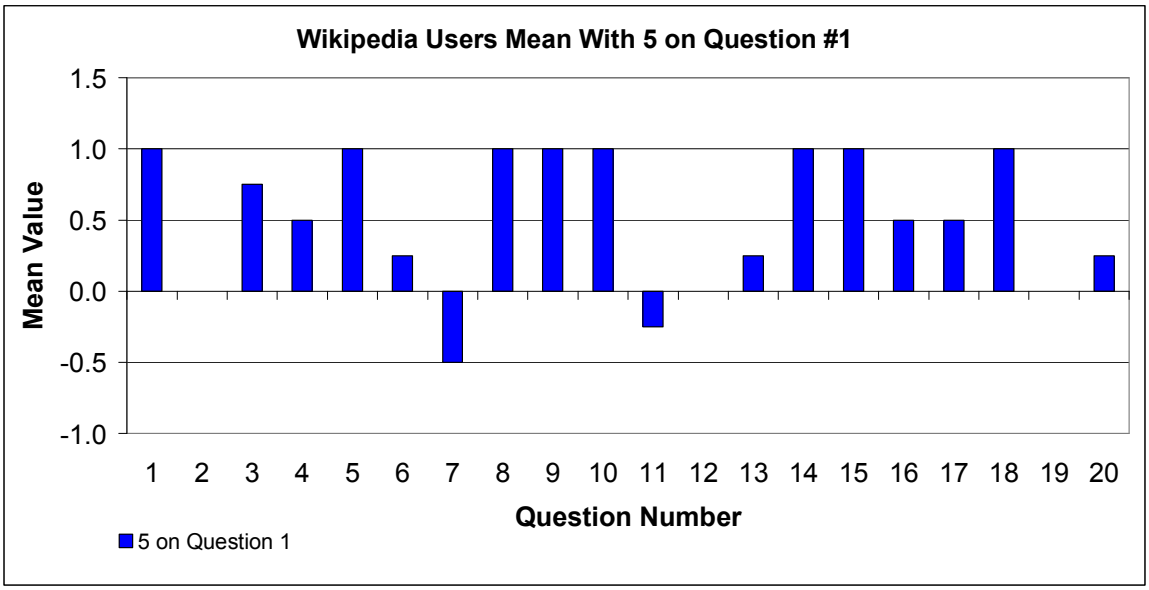

Figure 37 - Social Acceptance of highest self-proclaimed knowledge Wikipedia user results by question.