A Study of Engineering Freshmen Regarding Nanotechnology Understanding

Kathy Lu
Virginia Polytechnic Institute and State University

Abstract

This study was conducted under the grand scheme of nanotechnology education and was focused on examining the nanotechnology readiness of first-year engineering students. The study found that most students learned the term 'nano' from popular science magazines or as a measurement unit; less than 5% of the students learned 'nano' through nanotechnology education. The study also showed the students' obvious optimism on nanotechnology but lack of deep understanding and commitment to 'nano'. Among the students studied, female students were more enthusiastic in learning and participating in nanotechnology, but they were more likely to accept false nano-knowledge. The study showed that there is a clear need to understand the students' personal views on many nanotechnology issues before technical issues can be properly addressed.

Introduction

Nanotechnology is imaging, measuring, modeling, and manipulating matter at dimensions of roughly 1-100 nm, where unique phenomena enable novel applications. This emerging research area cuts across many scientific disciplines and encompasses a broad and varied range of materials. The drive behind nanotechnology activities is the continued development of nanomaterials and the constant stream of new properties and capabilities that are being discovered. These innovations make possible an ever-increasing number of applications with improved performances and the promises of competitive advantage and value creation. The use of nanomaterials in industries is increasingly being seen as one way of gaining advantage in the marketplace [1]. Example sectors of nanotechnology application are defense, homeland security, health care, information technology, transportation, and civil infrastructure.

Compared to the extremely active nano-research, nano-education has only received more emphasis in the recent few years [2-5]. Many U.S. institutions incorporated nanotechnology education into the classrooms and laboratories of well-established curricula [6-8]. University of Washington, Seattle launched a pioneering PhD program in nanotechnology [9]. University of Central Florida developed a "nanotechnology ethics" seminar series specifically for students participating in the National Science Foundation funded Research Experience for Undergraduates program [10]. Australia established the first nanotechnology undergraduate degree in 2000 [11]. To circumvent the problem of accessing expensive nanoscience research facilities, researchers have also devoted efforts to establish a virtual Nanoscience Laboratory to simulate the nanoresearch environment and interface with actual equipment [12]. Along with the educational reform, governments around the world are also taking proactive steps in developing a trained nanomanufacturing workforce for nanotechnology. In 2001, the U.S. National Science Foundation stated that developing a broadly trained and educated nanotechnology workforce presents a severe challenge to educational institutions, which favor compartmentalized learning. In 2004, the U.S. National Nanotechnology Initiative listed developing a skillful workforce to advance nanotechnology as one of its four goals [2,4]. In parallel, concerns have emerged about the potential health, environmental, and societal impacts of nanoscale science and technology, as voiced by the Action Group on Erosion, Technology, and Concentration (ETC Group) and Greenpeace [13]. There has also been much hype around nanotechnology, both by those who want to promote it and by those who have fears about its potentials. At this important crossroads, engineering students, the main workforce for future nanotechnology innovations, need to be educated on these important issues and should understand the potentials as well as the liabilities of nanotechnology. More specifically, do the students have a good technical understanding about the fast-growing nanotechnology field? Are the students ready to embrace the enormous potentials brought by nanotechnology? Are the students prepared to take on the technical challenges and the societal responsibilities of nanotechnology? Also, a culture of nanotechnology learning needs to be created to nourish the creativity of individual students, promote education of students of all types in nanoscale science and engineering, and campaign for societal acceptance of new nanoscale inventions in a responsible way. Nanotechnology needs to start with recruiting talented students into this exciting field, continue with a passion for discovery and innovation, and conclude with nano-knowledge and technology transfer to the future generations.

Recently, an Internet survey of 3909 respondents indicated that in the general public women are much less enthusiastic about nanotechnology than men [14, 15]. This trend is alarming in that nanotechnology is an emerging field that spans over food production, medicine, environment, and aerospace research; gender should not make such a difference in this diverse and new field as it has shown in some traditional engineering disciplines, such as Engineering Science and Mechanics and Mining and Minerals Engineering. Young people can be discouraged from entering nanotechnology careers by the popular stereotypes discovered in this survey. There is a clear need to understand how nanotechnology is perceived and projected on university campuses, identify trends that may hinder the advancement and innovation of nanotechnology, and take remedial actions such as educational reform or public information campaign. Only through understanding the students' viewpoints and eliminating discouraging factors in nanotechnology education can the best engineering students be produced to face the grand challenges presented by nanotechnology. This study emphasizes the understanding and evaluation of the entry state of engineering students, namely, freshmen.

Classroom environment approach

This research was conducted under the grand scheme of nanotechnology acceptance and understanding as a precursor for nanotechnology advancement. Because engineering is a pillar discipline and major player in nanotechnology, engineering students are the natural candidates for this study. Since this was the first study within Virginia Tech engineering discipline trying to examine students' perception on nanotechnology, the study was restricted to first-year engineering students only. First-year engineering students are new to engineering field as a whole with no significant exposure to nanoscale education and research, and they are relatively consistent on age and engineering education level compared to the more senior students who have had varied experience and technical exposure during college education. This provides a comparable starting point without unintentionally biasing the study results. By taking these measures in the study, different observations in the survey results should mainly come from nanotechnology understanding and acceptance differences among the students. Since classroom teaching and learning are the most essential components of college education, this study was conducted by creating a classroom environment with specific issues regarding nanotechnology education and careful control of the participating student population.

In this study, the participating students' perception on the societal impact of nanotechnology was examined. A comprehensive questionnaire was created regarding the benefits and harmful consequences of nanotechnology to mankind, to science, and to economy (see appendix). Questions were also specifically devised to better understand engineering students' ability to distinguish nanotechnology hype from pseudoscience. For the question format, there were multiple choice questions with the students being asked to select one of five possible responses: a) strongly disagree, b) disagree, c) neutral, d) agree, and e) strongly agree. There were also open-ended questions to solicit written comments and descriptive answers. After the questionnaire was prepared, freshman participants were recruited through multiple email advertisements within the College of Engineering at Virginia Tech. Gender and ethnicity information of the students was gathered before they were admitted for the study. The large quantity of respondents (~100) required that only a limited number of participants (36) be accepted based on the designed ratio of gender and ethnicity in the study group. However, the ethnicity and gender of the respondents heavily favored Caucasian males. To recruit some specific minority groups, the advertisement was sent out multiple times to the targeted groups. Still, only limited numbers of participants for some demographic groups were achieved as shown in Figure 1. But the overall demographic distribution was fairly representative of a typical engineering class on a campus. While the number of participants is small, simple increase of participants would alter the student ratios designed because of limited minority students available. Also, our parallel work on 90 high school rising juniors and seniors supports our results. Since that work is focused on a slightly different population through a two week summer residential camp called C-Tech[2], the results are not included here.

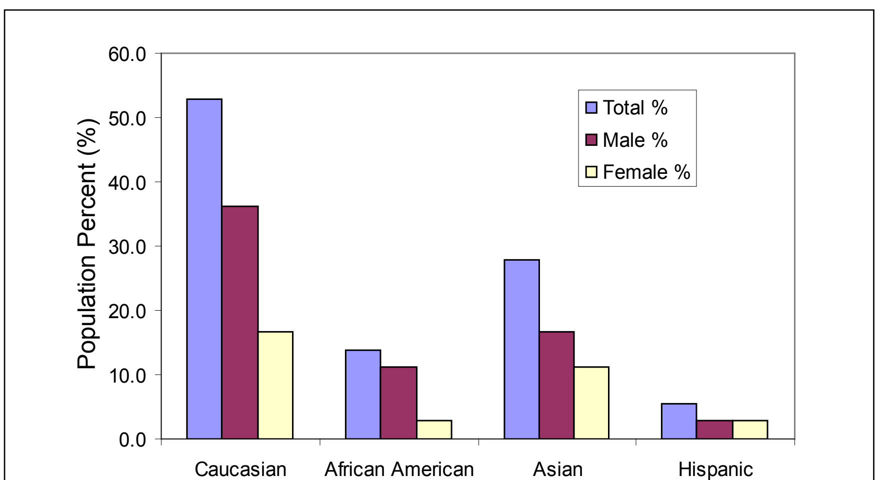

Figure 1. The demographic distribution of the 36 participants in the study.

Analysis of response results

1. Basic understanding of 'nano'

The first effort was to understand how much factual information the students knew about 'nano'. The question asked was: *'When was the first time you read or heard about the word "nano" applied to an engineering context? In two or three sentences, define nanotechnology.'* Among the responses that indicated a clear source, the answers were grouped as shown in Figure 2. As it showed, 50% of the students were introduced to the term 'nano' from popular science magazines. For the 32% of the students who learned 'nano' in the classroom, they often learned it as a measurement unit and were not taught any connection with nanotechnology. Less than 5% of the students learned the term 'nano' in a research lab. As well known, students' reasons for choosing an engineering field depend on early interest and exposure; very often the students will not pursue a new field if they know nothing about it. However, Figure 2 shows most engineering freshmen have none or very limited exposure to nanotechnology on a technical level. More proactive approach is needed in exposing engineering students in nano-education activities by providing lecture courses or lab hands-on nano-experiences. However, our current education curricula seem to reflect the typical "building block" approach and are not adequately addressing this issue. In their first year, engineering students take "skill" courses to meet the fundamental engineering education needs. In their second year, the students obtain a preliminary understanding of their majors through introductory classes. In their third year, the students dig into their 'would-be' field through specialized topics and some selective courses. And finally, in their fourth year, the students get to see how it all fits together through labs and design projects [16-18]. However, 25-50% students transfer/drop out of the engineering program due to a lack of curricular connection with real world problems even though engineering is the most 'tangible' field to our society. If not timely addressed, engineering students' lack of understanding and involvement in 'nano' can become another aspect of this bigger issue. To retain engineering students' interest in nanotechnology and encourage their involvement in nano-development and applications, there is a need to provide them with nano-related activities since the beginning of college education. Involving undergraduates early in nano-education can go a long way in strengthening nanotechnology advancement and increasing nanotechnology skilled workforce supply.

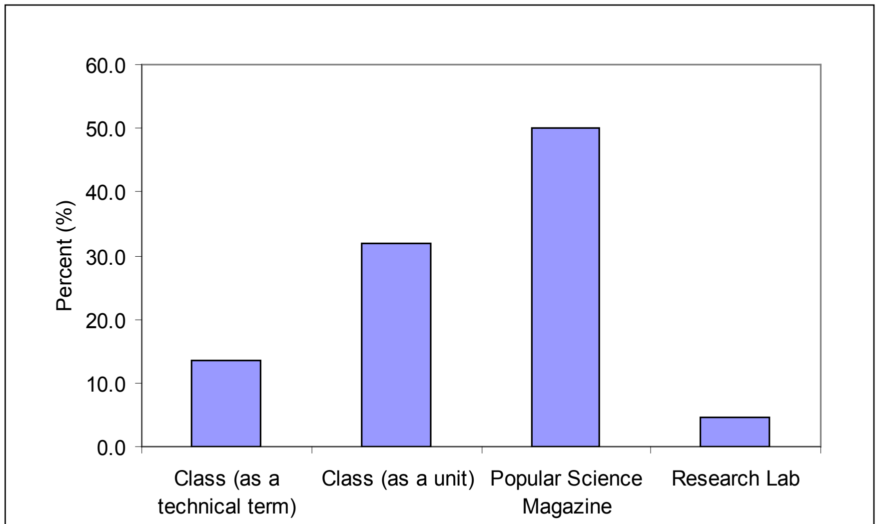

Figure 2. Sources that engineering freshmen first encountered the term 'nano'.

2. Acceptance and optimism of nanotechnology

With no thorough understanding or direct exposure to nanotechnology development, the students nevertheless expressed overwhelming acceptance in response to nanotechnology's potentially impact on our society. As shown in Figure 3, 94% of the participating students agreed or strongly agreed that nanotechnology will change the way Americans live. Only 3% of the students disagreed with such a statement. To examine the students' view on the positive or negative impact of nanotechnology on the way Americans live, we asked if the benefits of nanotechnology strongly outweigh the harmful impact. 62% of the students agreed this is the case while only 17% of the students disagree. The students showed the same level of optimism when asked if nanotechnology will be a huge and important industry in the future (Figure 4). 91% of the students agreed or strongly agreed with the statement while only 3% of the students disagreed with this prediction. These results demonstrated that engineering freshmen, as a specific group in our society, are very enthusiastic and optimistic about nanotechnology and believe it will change our society in a positive direction. This easy belief in the benefits of nanotechnology seems to mainly come from general public information such as news media and popular science magazines, given how little they have been exposed to nanotechnology education. Nanotechnology undoubtedly has been presented in a very positive light from the scientific community. However, cautions should be taken about the students' overwhelming acceptance and optimism of nanotechnology. Students could be baffled when factual information is presented about 'nano', which includes both the pros and the cons. It could take unexpected efforts to 'un-do' some of their learning in classrooms or labs as we will discuss later.

To present the students' responses in a factual manner, a few answers are listed here directly from the discussion questions. An examination of these written responses can help to provide deeper insights into the students' levels of understanding regarding nanotechnology. One of the questions asked was: *"What is your opinion about the societal impact of nanotechnology (the way we live, think, and behave)?"* The following answers were received:

- Improvements in everyday life: medicine, smart fabrics, entertainment, computing. Nanotechnology could be used to improve every aspect of life.
- Nanotechnology changes pretty much every aspect of life for many people but in ways not generally recognized. It seems that the miniaturization of electronics has as a whole increased communication and connectivity and thus brings the world closer together.
- It has hit us with a whole new perspective of materials and objects, and has allowed us to look more in depth into nature and consumer products we are producing, allowing further technical advances. For example: computers, nanotech chips, DNA structures, and modeling using organic materials in the nanoscale for better applications.
- Nanotechnology would likely improve the quality of life, and possibly extend a person's life itself. It will open up a world of possibilities we cannot yet imagine.
- Everyday objects/devices will be made smaller, and thus easier to use. Things will become more portable. Diseases/illnesses will have a greater chance of being cured. Cell phone communications would improve; this would make communicating in different parts of the world much easier.

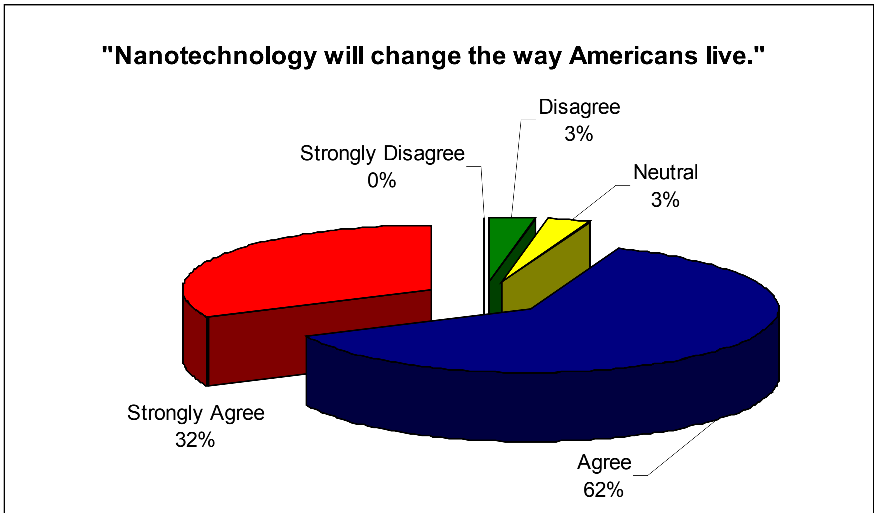

Figure 3. Total students' responses to the question that nanotechnology will change the way Americans live.

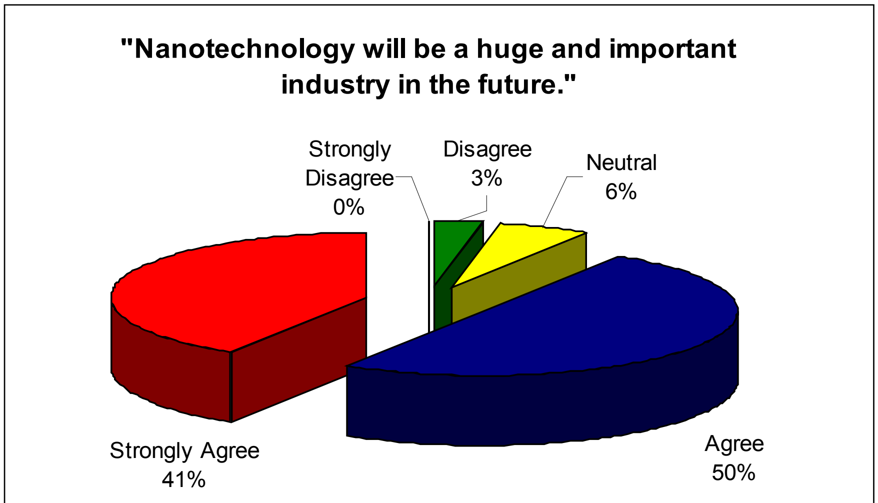

Figure 4. Total students' responses to the question that nanotechnology will be a huge and important industry in the future.

However, when the issue was probed further by asking the potentials and the responsible development of nanotechnology: *"Do you truly believe nanotechnology will deliver all the great promises that researchers have foreseen? Do you think we can handle all the issues that nanotechnology brings (good and bad)?"* the following answers were received:

- At this point nanotechnology seems mostly good, because after all, that's why we are investing in it. But as it develops further, problems will arise. However, bad things reflect the good things, so we will work on it to make it good.
- I'm not sure if it will be as wonderful as everyone thinks it will be, but indeed beneficial. I don't think that everyone in this country will ever be able to handle issues that come with new technology, but we will see in the end all the good issues outweigh the bad issues.
- Nanotechnology has great potential; now whether or not it will reach that potential or be accepted is a question that we'll have to wait and see. We can handle the good, but I doubt we can handle the bad.
- Yes I think a great number of advancements can be made with the progress of nanotechnology. Although we may not be ready for

these advancements we will have to adapt.

In contrast to the overwhelming optimism observed in Figure 3 and Figure 4, the second set of responses clearly showed the students' reservation on the capacity and negative impact of nanotechnology. This means that the students' readiness on nanotechnology may be founded on an intuitive level and needs to be further supported by solid knowledge through nano-education. This issue is even more obvious when the third question was examined: *"What fallacies are associated with nanoscience?"* The example answers are:

- I'm not sure; I've only heard positive comments about the field.
- The only fallacy I perceive is with the ethics behind it. Technology and knowledge advance what scientists can do, but the implications behind the technology are overlooked and therefore dangerous to society.
- Star Trek.
- We could not come up with any fallacies in the nanoscience field.

These responses again formed a sharp contrast with Figure 3, Figure 4, and the first set of comments. This clearly indicates that the students have certain level of understanding in nanotechnology, similar to other topics in engineering. But they can easily change viewpoints when presented with different evidences or confronted with challenges. Engineering freshmen year is a critical time for educators to retain the students' early interest in 'nano'. Otherwise, many talented students may be lost by having their curricula and activities populated with contents that do not match well with their study interests or are contradictory to what they know, or simply by a lack of encouraging climate in nano-education. Also, it indicates that cautions should be taken about how to teach a controversial 'nano' issue in the classroom. The unquestioned acceptance of nanotechnology can create a scenario that the students will simply accept anything without critical thinking or questioning. Educators must carefully deliver the correct knowledge of nanotechnology and address various mis-perceptions. Otherwise wrong concepts and biased understanding on nanoscience and nanoengineering can be imparted to the students. The blind acceptance of nanotechnology (sometimes wrong contents) is a serious issue that should not be ignored.

3. Gender and diversity

To examine whether gender plays a role in nanotechnology acceptance and enthusiasm, a question was asked about whether nanotechnology research and related industry are more appropriate for one gender or the other by nature. The responses from both genders are shown in Figure 5. Male students tended to have a stronger opinion and believe that nanotechnology is not preferable for one gender while female students were more neutral on the question. It seems that women held some reservation even though the specific reasons were not articulated. When the discussion question "Is gender a concern in choosing or not choosing nanotechnology as one's field?" was asked, most students gave a succinct 'no.' Among a few less certain answers, two female students answered *"It shouldn't be, but sometimes it is.'* and *"I sure hope not."* These answers clearly indicate concern and reservation on this issue. For the male students, the answers were *"Yes, gender will always be an issue to someone.", "Don't think so, although it is a fact that more men than women pursue fields in science & engineering.", "Potentially despite the fact that it shouldn't."* From these answers, it seems that male students tended to take this issue in a more resigned manner while female students expressed uneasiness on this subject.

This trend was observed again when the students were asked another question: *"Because matter behaves differently at the quantum level, nanotechnology will eventually make perpetual motion machines, anti-gravity devices, and time travel machines physically possible* (Figure 6)." This question was designed specifically to test the students' ability in differentiating true science from pseudoscience. Higher percent of female students answered that theoretically impossible things such as perpetual motion machines, anti-gravity devices, and time travel machines will happen with nanotechnology. This consistently indicates that even though female students are more enthusiastic in learning and participating nanotechnology, they tend to accept nanotechnology in various forms. The exact cause deserves further study. Nevertheless, this tendency should raise the instructors' attention in nanotechnology education. In both classrooms and research labs, special efforts should be made in pointing out the right and wrong in various nanotechnology issues. This awareness is critical to prepare all of our students' involvement in nanotechnology and eventually transforming them into outstanding scientists.

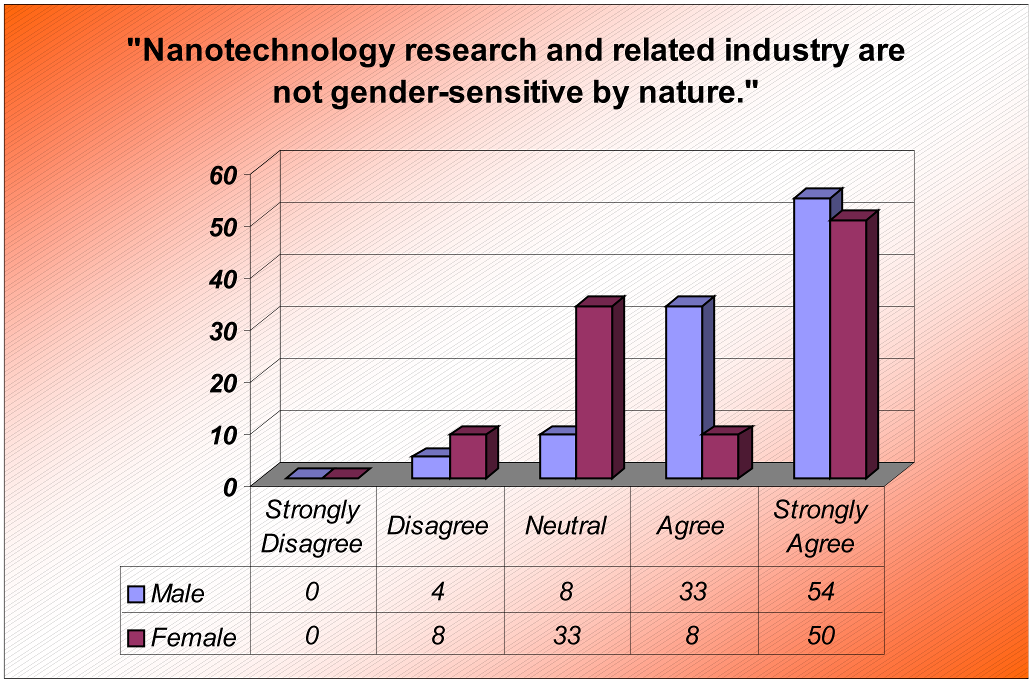

Figure 5. Response difference from the question: nanotechnology research and related industry are not gender-sensitive by nature.

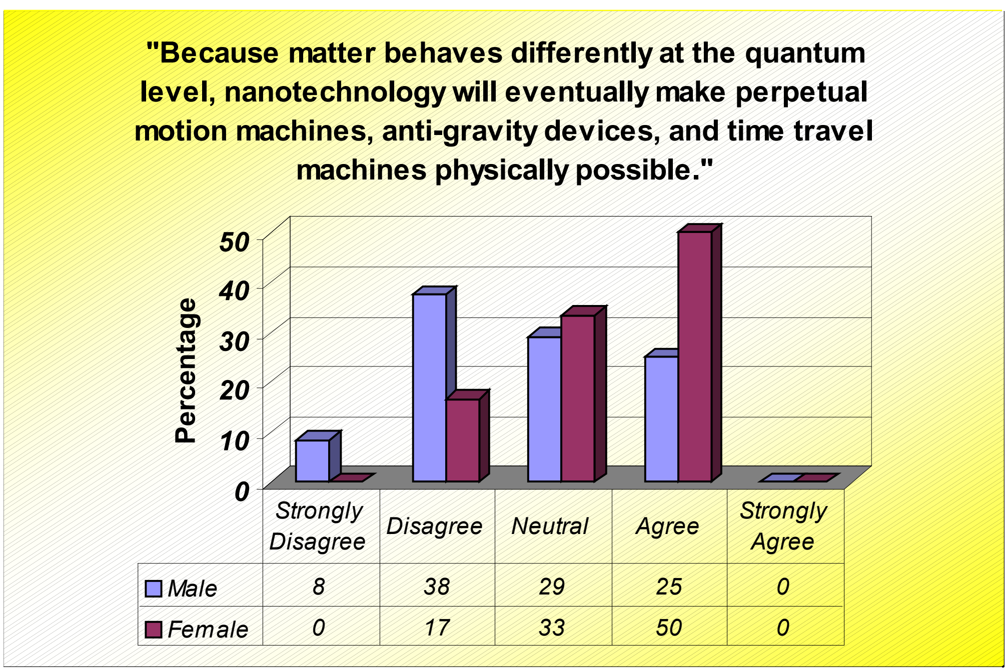

Figure 6. Response difference from the question: because matter behaves differently at the quantum level, nanotechnology will eventually make perpetual motion machines, anti-gravity devices, and time travel machines physically possible.

4. *Ethnicity effect on nanotechnology perception and interest*

As to whether ethnicity plays a role regarding nanotechnology study and research, a question was designed as: "Some scientists have predicted great advancement on military capabilities from nanotechnology, so we should research nanotechnology to improve our na-

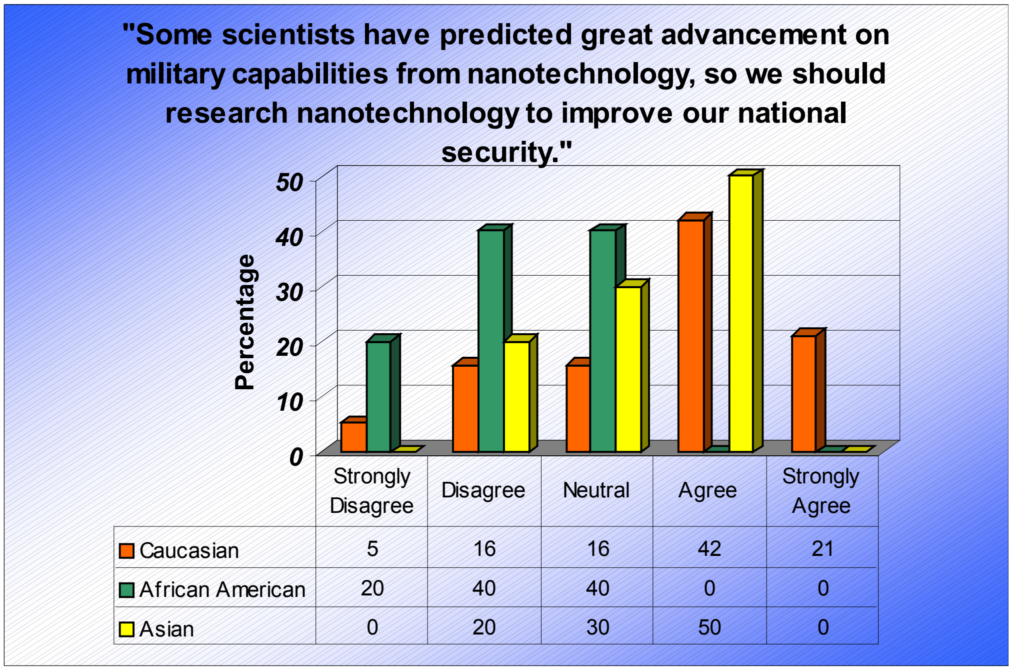

Figure 7. Response difference from the question: some scientists have predicted great advance ment on military capabilities from nanotechnology, so we should research nanotechnol ogy to improve our national security.

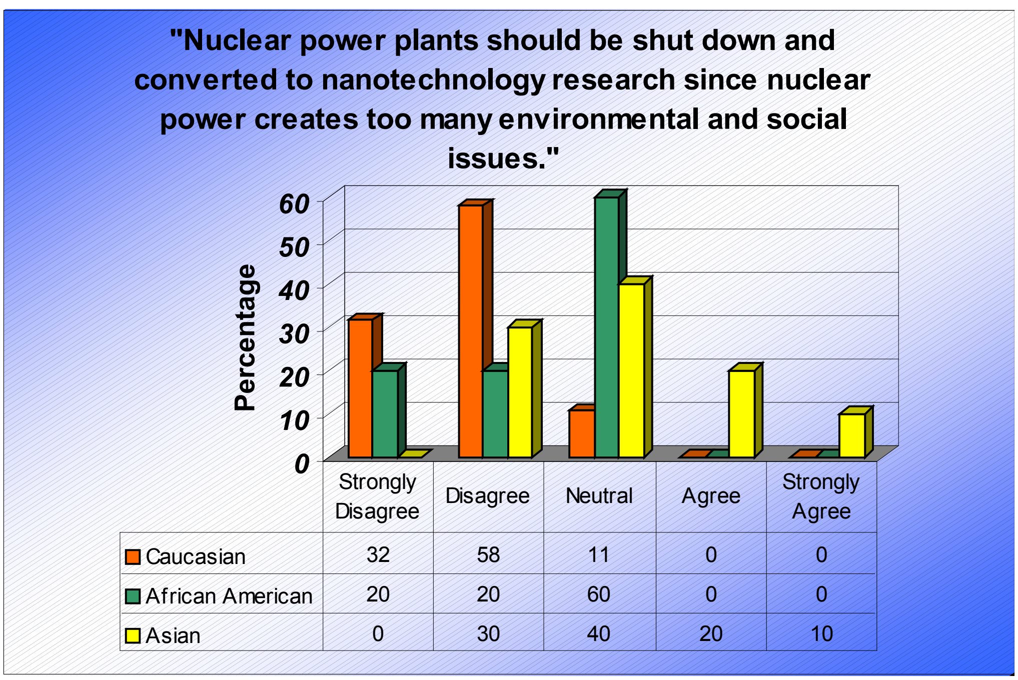

Figure 8. Nuclear power plants should be shut down and converted to nanotechnology research since nuclear power creates too many environmental and social issues.

tional security (Figure 7)." The African American students were observed to disagree more on this issue than the Asian or Caucasian students (see Figure 1 for demographic data). Interestingly, when another question, "Nuclear power plants should be shut down and converted to nanotechnology research since nuclear power creates too many environmental and social issues," was asked, more African American students tended to think it is a feasible idea along with the Asian students (Figure 8). While it is well known that many technical issues can have complex social or political impacts, this is an area that should not be ignored or delayed in the 'nano' education area. If this aspect is not properly addressed, the students can quickly change their views when nanotechnology is linked to specific applications, which can unexpectedly hinder or accelerate nanotechnology advancement. With the understanding that the reason for giving certain answers can come from all different aspects (such as education, family background, personal experience, political views, etc), the responses to these questions clearly indicate that the students' personal views on these issues need to be understood before scientific issues can be properly addressed and our next generation engineers can be properly educated.

Conclusions

This research was conducted to provide insight in nanotechnology readiness among engineering freshmen and its implication in the way nanoscale science and engineering education should be carried out. Overall, the students showed clear optimism on nanotechnology's potentially positive impact on the society. Male students believed nanotechnology and related industries are not preferably for one gender but not all the students were at the same starting point. Female students tended to think slightly the opposite. Also, the females tended to accept more willingly on different aspects of nanotechnology than the males. Ethnicity difference did affect the students' viewpoint on specific issues.

This study is by no means definitive, and, along the process, it has raised many more questions. On top of what has been accomplished in the findings, the work clearly indicates the need to utilize the acquired knowledge regarding the engineering freshmen and foster a better environment for nanotechnology education. Based on this work, strategies should be devised to find effective ways to keep talented female students in nanotechnology fields, such as by offering research experience in the labs, special interest group discussions, field trips to nano-research centers, and nano-related outreach activities. In the classrooms, the instructors should be mindful about the societal context of the nanotechnology in discussion. Ample time should be offered for the students to express their concerns and viewpoints. If a specific nanotechnology question is prone to multiple, sometimes contradictory, interpretations, the instructors should provide a conducive environment in developing students' critical thinking skills. This will prevent blind acceptance or complete rejection of nanoscience and nanoengineering from the students.

Acknowledgments

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Kathy Lu received her MS and PhD in Materials Science and Engineering from Ohio State University in 1999 and 2000 respectively. From 2000-2001, she worked at Penn State University as Director of Materials Processing. From 2001-2004, she worked in industry as a Materials Processing and Development Scientist. Since 2004 she has been an Assistant Professor with Virginia Polytechnic Institute and State University. She has published about 70 papers in the areas of nanomaterials, powder processing, sintering, and composites. She teaches Nanomaterials and Powder Processing classes. She is a member of the American Ceramic Society, Materials Research Society, APMI International, and American Society for Engineering Education.

Appendix: Questionnaires used for this study.

Table 1. Multiple choice questions with five possible responses: a) strongly disagree, b) disagree, c) neutral, d) agree, and e) strongly agree.

1	Nanotechnology will change the way Americans live.
2	The products designed using nanostructures will be too expensive for the majority of people to buy.
3	I am interested in studying nanotechnology.
4	Development of nanotechnology should continue, because the benefits strongly outweigh the harmful results.
5	Some scientists have predicted great advancement on military capabilities from nanotechnology, so we should research nanotechnology to improve our national security.
6	Our understanding about the benefit and harm of nanotechnology is clear; all the efforts should be made for research.
7	Nuclear power plants should be shut down and converted to nanotechnology research since nuclear power creates too many environmental and social issues.
8	Because matter behaves differently at the quantum level, nanotechnology will eventually make perpetual motion machines, anti-gravity devices, and time travel machines physically possible.
9	Nanotechnology will enhance the abilities of human beings, so therefore it cannot threaten the well-being of mankind.
10	Nanotechnology will be a huge and important industry in the future.
11	Nanotechnology research will allow us to design e-meters and aura cameras that can measure the human spirit.
12	Nanotechnology is simply a buzz word in science and engineering to create a halo effect and give scientists something new to talk about. It is a scientific fad.
13	Nanotechnology research and related industry are not gender-sensitive by nature.
14	Nanotechnology may be a good thing, but I don't see why I should get into a field that is totally irrelevant to the environment I grew up in.
15	Teachers have encouraged me to study nanotechnology.

Table 2. Discussion questions.

1	What is your opinion about the societal impact of nanotechnology (the way we live, think, and behave)?
2	How will nanotechnology improve or harm science as a whole?
3	How will nanotechnology affect products that industry produces, and thus our whole economy?
4	With all the excitement and new discoveries in nanotechnology, how will it affect other scientific programs, such as physics, space exploration, robotics?
5	Are ethnicity and gender a concern in choosing or not choosing nanotechnology as one's field?
6	Do you truly believe nanotechnology will deliver all the great promises that researchers have foreseen? Do you think we can handle all the issues that nanotechnology brings (good and bad)?
7	What fallacies are associated with nanoscience?
8	When was the first time you read or heard the word "nano" applied to engineering context? In two or three sentences, define nanotechnology. If you never heard abut 'nano', please simply answer so.