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Perspectives

Nanotechnology and the public: Effectively communicating nanoscale science and engineering concepts

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Abstract

Researchers are faced with challenges when addressing the public on concepts and applications associated with nanotechnology. The goal of our work was to understand the public's knowledge of nanotechnology in order to identify appropriate starting points for dialog. Survey results showed that people lack true understanding of concepts associated with atoms and the size of the nanoscale regime. Such gaps in understanding lead to a disappointing lack of communication between researchers and the public concerning fundamental concepts in nanoscale science and engineering. Strategies are offered on how scientists should present their research when engaging the public on nanotechnology topics.

The topic of nanotechnology is increasingly capturing the public's interest. With more frequency, articles appear in the technology and business sections of our local newspapers, presenting new nanoscale science and engineering-related research applications and the promise of future investment in the field (Roco, 2004). School-aged children are increasingly exposed to the idea of nanotechnology as a key to their high-tech future through movies, comics, and television shows. With this rise in familiarity comes interest in the topic; leading nanoscale science and engineering researchers are frequently asked to speak in public forums, answer questions posed by reporters, and engage school-aged children in both K-12 classrooms and informal education settings.

Unfortunately, researchers may not always be effective with these audiences. A gap occurs between baseline understanding assumed by the researcher and the majority audience's true comprehension of fundamental concepts (Pecora et al., 2003). For example, it is often assumed that people can actually comprehend that elements are the building blocks of all matter if they know basic facts about atoms. Additionally, it is assumed that people familiar with the metric system can truly conceptualize the minute size of the nanoscale regime. These erroneous assumptions lead to a disappointing lack of communication between scientists and the public concerning fundamental concepts in nanoscale science and engineering.

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Often the researcher's enthusiasm comes across, leaving the audience wowed, while the goal of conveying the underlying concepts of nanotechnology is left unmet and understanding of the research by the public is not achieved.

In addition to conveying the exciting potential of the field, true understanding of targeted scientific concepts has many significant advantages. A better-informed public can make rational decisions concerning policy and public funding of research (Sturgis et al., 2005), with higher levels of knowledge corresponding to more positive public perceptions of the new technology and more trust in the developers of such technology (Cobb & Macoubrie, 2004). Because the vast majority of the public will form judgments based on information gleaned in the mass media (Scheufele & Lewenstein, 2005), it is essential that reporters understand the basics so that they can more accurately convey new nanotechnology applications to their readers. Likewise, school-aged children, particularly girls and minorities, who expand their understanding of basic science concepts can be kept in the education pipeline and prepared to follow an education path that may lead them to science and engineering careers (NSB, 1999; NSB, 2003; Van Langen & Dekkers, 2005). Retention of these students is imperative for the continued health of the science and engineering fields and the active involvement of researchers may foster this retention and bolster student achievement (NSF, 1999).

This paper presents our research on public understanding of nanotechnology and related scientific concepts. The goal of this study was to define the public's baseline knowledge of nanotechnology and determine what audiences know so that an appropriate starting point for dialog can be identified. We also present strategies for building on prior knowledge, reinforcing understanding of basic concepts related to nanoscale science and engineering, and bridging the gap to the exciting, cutting-edge research that scientists want to convey.

In order to define the public's baseline knowledge of nanotechnology, a seven-question survey was developed. This small questionnaire tested the public's knowledge of size scale, atoms, and nanotechnology as well as their attitudes towards nanotechnology. The questionnaire was administered at two Wisconsin public schools, a children's science museum and a large shopping center. In total, 495 people ranging from 7 to 91 years-of-age with varying levels of education participated in the study (Figure 1).

Knowledge of the nanometer size scale was assessed first. Respondents were asked to record the smallest thing that they could think of. The given answers were broken down into the following categories: 1. small visible object (e.g. bugs, grain of sand, point of a needle, raindrop); 2. atom; 3. microscopic objects (e.g. cells, bacteria, molecules); 4. sub-atomic particles (e.g. electrons, protons, neutrons, quarks); and 5. other or n/a. This last group included answers that were not objects, but measurements, answers that could not be deciphered, and nonsense objects. Fifty-four percent of 2nd–4th graders reported ants, bugs, and germs to be the smallest things that they could think of. By 6th grade, many children began to include atoms and cells, and by 8th grade, 67% answered atom. Overall, 57% of 6th–8th graders answered atom. This trend roughly corresponds to the years in school when atoms are first taught. High school students' answers became less uniform, with only 36% of 9th and 10th graders answering "atom," a dramatic decrease from the

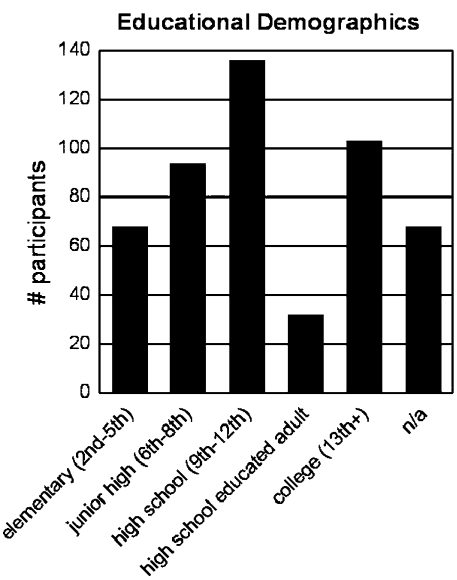

Figure 1. Demographics of study participants. A total of 495 people with varying levels of education participated in the study. Response n/a indicates surveys where the respondent chose not to provide information on their level of education.

middle school demographic. Eleventh and 12th graders more consistently answered with atom (46%), and 32% answered some type of sub-atomic particle. Post-high school educated adults were more consistent with the older high school demographic with 33% reporting that the smallest thing that they could think of was an atom and 45% reporting sub-atomic particle (Figure 2).

Respondents were next asked to rank the relative sizes of a cell, bacterium, atom, and water molecule in order to obtain a quantitative measure of their understanding of size scale (Figure 3). Forty-five percent of respondents answered that an atom was the smallest item but did not correctly order the others, while 25% of respondents reported that an atom was largest item on the list. Only 7% of respondents correctly ranked all the items in order of size. However, respondents were more successful when ranking small, visible objects. Forty-five percent of the sample was able to correctly rank the order of a housefly, dust, eyelash and grain of salt, and 70% of participants reported that a housefly was the largest in the group while 55% ranked dust particle as the smallest. It is possible that some participants misread the first portion of the question and ranked items in order from smallest to largest, instead of as largest to smallest as the instructions indicated. Nevertheless, this scenario is unlikely, based on the high proportion of correct answers for the second portion of the question. It is more likely that individuals were better at ranking the relative sizes of small visible objects and had a harder time conceptualizing the sizes of microscopic and sub-microscopic objects.

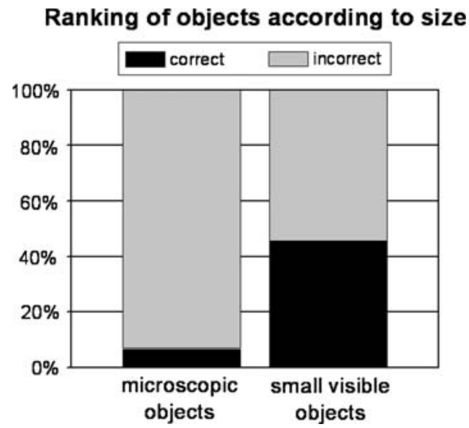

Figure 3. Aptitude for ranking objects in order of size. Participants ($n = 495$) were asked to rank microscopic and small, visible objects in order of relative size. Microscopic objects included a cell, a bacterium, an atom and a water molecule. Visible objects included a housefly, dust, an eyelash, and a grain of salt. Results indicate a lower level of conceptualization for microscopic objects.

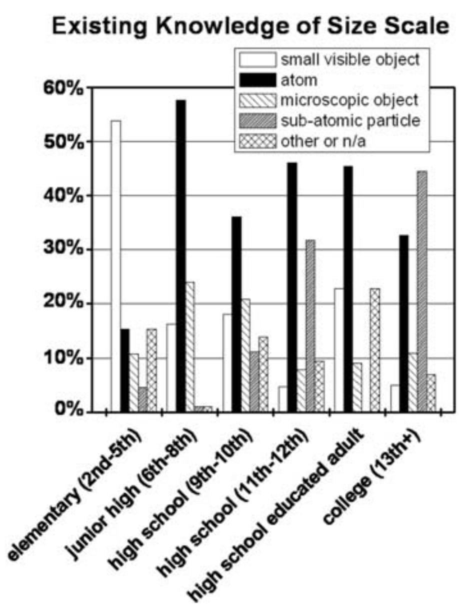

Figure 2. Existing public knowledge of the nanometer size scale. Participants ($n = 495$) were asked "What is the smallest object you can think of?" Answers are categorized according to education level. Data reflect a peak in knowledge about atoms at the middle-school level, roughly corresponding to the time at which students first learn about atoms.

People were then questioned about their existing knowledge of nanotechnology. In total, 41% of respondents reported that they had heard of nanotechnology. Of those, only 42% were able to correctly define it. Correct definitions included mentioning a type of technology and small size. When asked where they had heard of nanotechnology, the most prevalent responses were mass media outlets including television, magazines and newspapers. For example, 5 children mentioned hearing about nanotechnology from a popular cartoon, *Jimmy Neutron*, and 49% of respondents who had heard of nanotechnology had heard of it from the media (i.e. books, the Internet, magazines, movies, news, and television). Only 28% of participants had heard of nanotechnology from school or other people. All of these results are in good agreement with trends identified by national studies (Cobb & Macoubrie, 2004; Macoubrie, 2005; Scheufele & Lewenstein, 2005).

The remaining questions assessed respondents' baseline knowledge of atoms. When asked if they knew what an atom was, 79% reported yes. Of those, 74% answered 3 fact-based true/false questions about atoms correctly, indicating a solid fact-based knowledge of atoms.

In the later stages of surveying, additional questions were added to assess attitudes towards nanotechnology. Of the 495 total participants, only 135 answered the questions about attitudes. Therefore, data on attitudes reflect this smaller sub-set only. Respondents were first asked to rate specific attitudes on a scale of 1–4 with one being a negative attitude and four being positive. The questions were ordered such that "negative" and "positive" words were switched from line to line, in hopes of avoiding answers that were not carefully considered. All answers that were simply circled down the middle (e.g. all 4s circled) were discarded. When asked to choose between nanotechnology being "boring" (1) versus "exciting" (4), "uncomfortable" (1) versus "comfortable" (4), and "dangerous" (1) versus "safe" (4), the mean score was within 0.21 from the center of the scale, indicating a fairly neutral opinion on their relative comfort level with nanotechnology. For "unimportant" (1) versus "important" (4), the mean score was 2.89. A question asking respondents to choose between "harmful" (1) versus "beneficial" (4) showed the biggest deviation from average with a mean score of 3.13 (Figure 4). Respondents were also asked about their overall opinion of nanotechnology, shown in Figure 5. Most respondents felt neutral towards nanotechnology and its potential impact on their life and society, while 33% felt very excited or excited and 11% felt very worried or worried.

These data have important implications for researchers presenting their work to public audiences. Nanotechnology currently holds a relatively neutral or slightly positive position in public opinion (Cobb & Macoubrie, 2004; Scheufele & Lewenstein, 2005). Nanotechnology scientists and engineers must learn from the mistakes of other emerging areas of technology (Shelton & Sears, 2001), keeping the public's mind open to the field and its possibilities. The findings presented above indicate that the public thinks of nanotechnology as at least somewhat important, safe and beneficial. This is an advantageous starting point for conversations about current developments and research on nanoscale science and engineering topics because presenters are not on the defensive and audiences are open to learning about the topics. However, great care must be

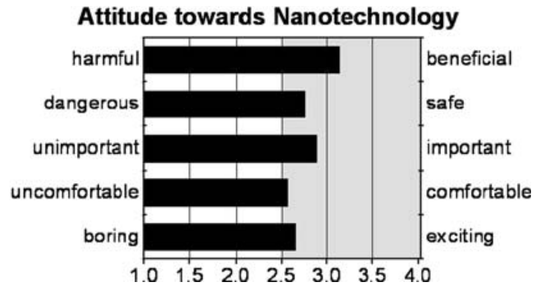

Figure 4. Public attitude towards nanotechnology. Participants ($n = 135$) were given five pairs of words and asked to rank specific attitudes on a scale of 1–4, with 1 being the most negative connotation and 4 being the most positive. The data represent an average of the responses and indicate a generally neutral overall attitude towards nanotechnology.

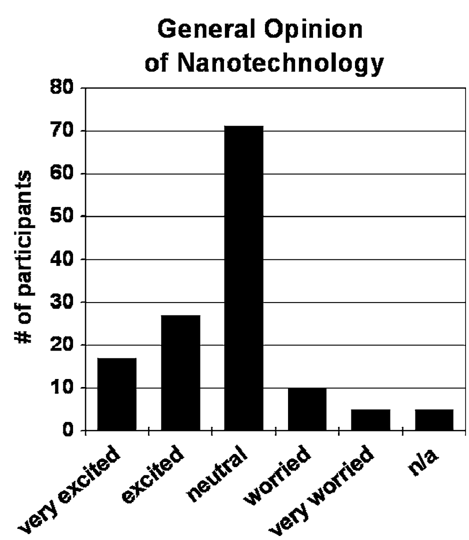

Figure 5. Results from the survey question that asked participants to circle the word that represented their overall opinion of nanotechnology and its potential impact on their life and society ($n = 135$). The overwhelmingly neutral opinion of nanotechnology is a favorable starting point for conversations about advances in the field.

taken to cultivate a positive public opinion and understanding of nanotechnology. Researchers should actively engage their audience in discussion, making sure to acknowledge the benefits and risks involved (Kasuya, 2004). Facilitating a discussion will help the audience have a better technical understanding of nanotechnology as well as ease their fears and concerns (Nisbet, 2005).

The data reflecting the smallest objects participants can think of (Figure 2) highlight a critical trend in scientific literacy. As students progress through school, their interest in and understanding of science can change. This is reflected in the dip in the number of respondents who reported an atom as the smallest thing that they could recall. This dip occurs in the transition from middle school to high school, with nearly half the number (34%) of 9th graders responding ''atom'' as compared to 8th graders (65%). Researchers can counteract this trend by sharing their research findings with student audiences and the public. Sharing one's research helps to create a scientifically literate public who are better informed to make important decisions about our world, while simultaneously showing children the opportunities of careers in the sciences. It is reported that people with science-related careers believe that informal learning experiences such as attending lectures and reading articles encouraged their early interest in science, reinforced their connections with school science courses, and planted in them science ideas that they still use today (Melber & Abraham, 1999).

The primary challenges for engaging with audiences about technology topics in general are creating a seamless dialog and understating what prior knowledge and misconceptions a specific audience brings (Best et al., 2005). Our data suggest that, although nearly half of the potential audience members have heard of nanotechnology, those individuals are not able to accurately define it. Of those survey participants that provided a definition of nanotechnology, answers ranged from ''being able to manipulate tiny things to do different things for scientific purposes'' to ''small beams of light.'' A clear definition of nanotechnology must be provided by the presenter in order to establish a common ground on which the conversation can be built. Inevitably this definition will involve the term nanometer, which is also poorly understood because it is so much smaller than what can be seen by the eye. As indicated in Figure 3, people have a difficult time conceptualizing objects they cannot see visually. Often researchers will resort to defining nanotechnology in terms of ''technology on the scale of atoms,'' assuming the concept of an atom is well understood by the high school-educated. However, this assumption is often erroneous. Although the vast majority of people say that they know what an atom is and can correctly answer a true/false question about the fact that ''atoms bond together to form molecules,'' audiences do not conceptually understand atoms. Data from this survey show that atoms do not come to mind when asked, ''What is the smallest thing you can think of?'' (Figure 2), and atoms are often not ranked as the smallest in comparison to other microscopic entities (Figure 3).

For the presenter, it is crucial to appreciate that people understand basic underlying facts about atoms and size but are often unable to conceptualize broader concepts. Effective communication requires stepping back, assessing the extent of prior knowledge, and re-teaching these basic concepts about atoms and size scale before jumping into the details of research. In our experience, such an approach can lead to a more positive attitude about the new technology topic being covered. To do so will entail a review of atoms as building blocks, the size of atoms, and the metric system.

The mechanics of the presentation should be carefully considered as well. A visual, pictorial review of the metric system can be effective (Levie & Lentz, 1982; van Dijk & Kintsch, 1983; Paivio, 1986; Thompson & Paivio, 1994; Mayer & Moreno, 1998), showing powers of 10 working from the macro range down to the nano. (For an example of a pictorial review of the metric system, see http://www.mrsec.wisc.edu/Edetc/SlideShow/index.html?nanoscale) It should also be noted that certain education levels are more likely to remember the atomic scale than others (Figure 2). One way to determine the level of understanding is to interact with the audience by posing questions. It has been shown that audiences are more receptive and retain more knowledge when then are actively engaged with the presenter as opposed to passively listening (Massey et al., 2005). Engaging the audience in this manner can elevate their excitement about the topic and encourage deeper, conceptual understanding of the technologies being discussed. Such dialog also increases the audience's confidence to explore science and makes them feel as though their thoughts and opinions are valuable to researchers (Rennie & Stocklmayer, 2003; Winter, 2004).

When finally poised to begin discussing the specific nanoscale science and engineering topic at hand, researchers must be very selective in what key concepts they try to convey. Flooding the conversation with too many new concepts can leave the audience overwhelmed and confused. The number of key concepts should be limited to two or three and they should be repeated several times and explained in several different ways to ensure that they are understood and remembered. Analogies to every day life can be effective for achieving better understanding, as can demonstrations and animations. Overall, researchers have found that good presentations contain: (1) a definition that lists each of a concept's critical features, (2) an array of varied examples and non-examples, (3) opportunities for learners to practice and/or discuss distinguishing examples from non-examples (Tennyson & Cocchiarella, 1986).

When done effectively, engaging the public in conversations about nanotechnology research can be a valuable and rewarding experience for both researchers and their audience. Not only will it bolster public science literacy and understanding of nanotechnology, but it will also pave the way for more favorable public policy on nanotechnology-related issues. Based on the results of our survey, we have presented guidelines for starting a dialog with the public, keeping in mind their existing knowledge of and attitudes towards nanotechnology. We found that less than half of the respondents in our survey have heard of nanotechnology, and of those who were familiar, fewer than half could correctly define the term. We also found that the majority of the public's exposure to nanotechnology comes from media outlets, such as television, movies and books. Most importantly, we found that factual knowledge of atoms and the nanometer size scale does not translate to conceptual understanding of these topics. This critical gap in comprehension is a fundamental stumbling block in the communication between researchers and the public. Making accommodations for this disparity by including brief, visual reviews of basic nanoscale concepts can bridge this gap in comprehension and result in effective communication of nanoscale science and engineering concepts.

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