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Perspectives

The current state of public understanding of nanotechnology

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Abstract

The growing importance of nanotechnology in industry and society has not been accompanied by a widespread understanding of the subject among the general public. Simple questions to initially probe the smallest thing that people can see and can think of reveals a divide in the understanding of the general public. A survey of 1500 individuals ranging in age from 6 to 74 has revealed a lack of knowledge of nanotechnology and especially a lack of understanding of the context of nanotechnology in the world that is too small to see. Survey findings are corroborated by in-depth interviews with 400 adults in studies of nanoscience literacy commisioned by University of California, Berkeley and Cornell in 2002 and 2004, respectively. In general, with the exception of 14–28 year olds, over 60% of respondents say they have never heard of nano or nanotechnology. The results suggest that the general public, especially middle-school children, has no firm foundation to understand nanotechnology and likely will continue to be equally impressed by credible scientific information as well as pure fictional accounts of nanotechnology.

Introduction

Nanotechnology, the deliberate manipulation of matter at size scales of less than 100 nm, holds the promise of creating new materials and devices which take advantage of unique phenomena realized at those length scales. Significant investments by industry, academia and government are being made with the hope that advances in nanotechnology will have a profound and positive impact on a number of aspects of our lives (Roco, 2003a, 2003b; Roco & Bainbridge, 2005). While investment in research and development are important, the public understanding of any emerging technology can have a dramatic effect on the implementation of that technology. Misconceptions and even a general lack of understanding can lead the public to react negatively to the emerging technology (Knight & Pierce, 2003; Friedman & Egold, 2005; Mills & Fledderman, 2005). The consequences can be devastating from market boycotts to lobbying for legislation that will not allow an emerging technology to be practiced. An often-cited example is genetically modified foods where both misconceptions and the failure to articulate the safety and benefits of the technology have led to resistance to introduction of new crops and an almost continuous public debate (Mehta, 2004; Service, 2004). While this debate should not be viewed as bad, the debate should be driven by a full understanding of the technology by all parties.

The need to raise public awareness of nanotechnology has been well documented (Weil, 2003; Morrissey, 2004; Schulz, 2002; Service, 2004; Waldron et al., 2005). Public understanding of nanotechnology has only partially been assessed largely through three studies (Bainbridge, 2002; Cobb & Macoubrie, 2004; Dowling, 2004). One Internet-based study revealed a relatively high level of awareness and support for nanotechnology but the general conclusions have been challenged given the nature of the instrument and the likelihood that respondents were more aware of the subject matter. In each of the other two studies, the public awareness of nanotechnology was relatively low, the public understanding was lower and when probed the public's accuracy in defining nanotechnology was even lower. A telephone survey of 1536 adults revealed that only 3.1% could correctly answer three true/false questions, only one of which probed a technical understanding of nanotechnology (Cobb & Macoubrie, 2004). These studies subsequently probed public opinion, an opinion which is not guided by any obvious understanding of the subject.

The study

To lay the groundwork for a traveling museum exhibition to help youth ages 8–13 to learn about nanotechnology, we conducted an extensive front-end study to gauge public perceptions of nanotechnology. The study was structured to determine public awareness and understanding of nanotechnology but then to help define their knowledgebase in a subtle fashion so as to more accurately assess their understanding. In a 4-month period, we interviewed and surveyed 1500 individuals exploring their awareness and understanding of nanotechnology. The survey instrument (Figure 1) contained both questions about the individual's perception of the world that is too small to see, their knowledge of terms including 'nano' and 'nanotechnology' and then their ability to correctly assign size order to the terms 'millimeter', 'micrometer' and 'nanometer' and the terms 'germ', 'molecule' and 'atom'. The latter two questions helped determine if the individual could place these terms in the correct order from biggest to smallest. While simplistic in nature, the survey probed public awareness and understanding, inquiring not only about their knowledge of specific terms but also their ability to put those terms in the appropriate context. Variables including education level and content could not be controlled and the differences in curriculum within different regions could account for the specific age at which a student was introduced to a given subject.

Researchers chose a stratified random sample of 1500 people in the United States. The sample included four strata of children and five strata of adults grouped by age. Youth data were analyzed by four age grades: age less than 8, age 8–10, age 11–13, and age 14–17. Adult data were analyzed for five age grades commonly used by demographers: age 18–22, age 23–28, age 29–39, age 40–59, and age 60+.

Because the primary target audience for the musuem exhibition was children age 8–13, 84% of the sample was under age 14 (36% of the respondents were age 8–10; 47% was age 11–13 and 1% was less than age 8). Teens (age 14–17) comprised 5% of the sample. Eleven percent of the sample was adults, with an equal percentage of adult respondents in each age grade.

To validate results of the larger survey, survey questions were asked in focus group interviews with a control group of 100 children. Adult responses were compared with answers to similar survey questions posed during in-depth interviews with 200 adults as part of a 2002 national survey on nano science literacy commisioned by the University of California, Berkeley (Spencer, 2003) and a similar survey of 200 adults during a Cornell Univeristy sponsored study at Epcot® in 2004 (Spencer & Angelotti, 2004). The responses from both the children's control group and the adult conversations mirrored survey responses.

Data for the survey were collected at 30 different sites spread across four states: Florida, Hawaii, New York, and North Carolina. Samples were ethnically and economically diverse, and included

1. How old are you? Boy Girl

2. What is the smallest thing you can see?

3. What is the smallest thing you can think of?

4. What is the lightest thing you can think of?

5. Have you heard of nano? YES NO

   If so, what do you think nano is?

6. Have you heard of nanotechnology? YES NO

   If so, what do you think nanotechnology is?

7. Put these in size order, biggest to smallest. ___milli ___micro ___nano
   (big = 3, medium = 2, small = 1)

8. Put these in size order, biggest to smallest. ___atom ___ germ ___molecule
   (big = 3, medium = 2, small = 1)

Figure 1. Survey instrument. Questions probed participant understanding of objects at the macroscopic, microscopic, and nanoscopic scales. The survey was designed to be a progression, taking the participant from the world they can see into the world they cannot see. Age and gender were recorded, as were responses to each question.

urban, suburban and rural sites. Some variables could not be controlled. For example, differences in curriculum within different regions affect the specific age at which a student is introduced to a given subject.

Results

When asked 'what is the smallest thing you can see?', almost all respondents offered significantly macroscopic items. Most of the individuals interviewed at all ages picked out something in their immediate environment when asked to name the smallest thing they could see. Cluster analysis showed that there was no obvious trend in the object offered as the smallest thing that they could see. Twenty six percent of young children up to age 11 chose animate objects including 'an ant', 'a bug', 'a flea', while others chose inanimate objects including 'a grain of sand', 'the tip of a pencil' and 'the dot on the letter i'.

The visible world and the imaginary world is often the same for children up to approximately age 11. The smallest thing that they can 'see' is the same as or similar to the smallest thing that they can 'think of'. In some cases children offered two different macroscopic objects, suggesting that they believed there might be a difference but not showing comprehension of the microscopic world. Starting at approximately 11 years of age, a greater percentage of children (52%) began to offer microscopic and nanoscopic objects for the smallest thing that they could think of. Twenty-five percent of these children offered nanoscopic items as the smallest thing that could think of. In the ages 14–17 category over 40% of teens chose more sophisticated answers that reflected some acknowledgement of the nanoscale world, including 'an atom', 'a proton', or 'a molecule' (Figure 2). Adults in general did not provide more sophisticated answers than children, with the exception of adults age 18–22, who listed the highest percentage of nanoscopic objects at over 50%. This trend could be due to the direct learning of the particulate nature of matter during the high school years in earth science and chemistry courses (Driver et al., 1994) and in college courses.

The term 'nano' was familiar to roughly 60% of individuals from age 14–59 (Figure 3). The term was less familiar to children under 14 and those 60 and over. Across the sample slightly more people had heard of 'nano' than 'nanotechnology'. The term nanotechnology was most familiar to those ages 14–28, and this age group could sometimes offer a correct definition (Figure 4). Some teens and young adults who did not know the word nano, had heard of nanotechnology, but could not

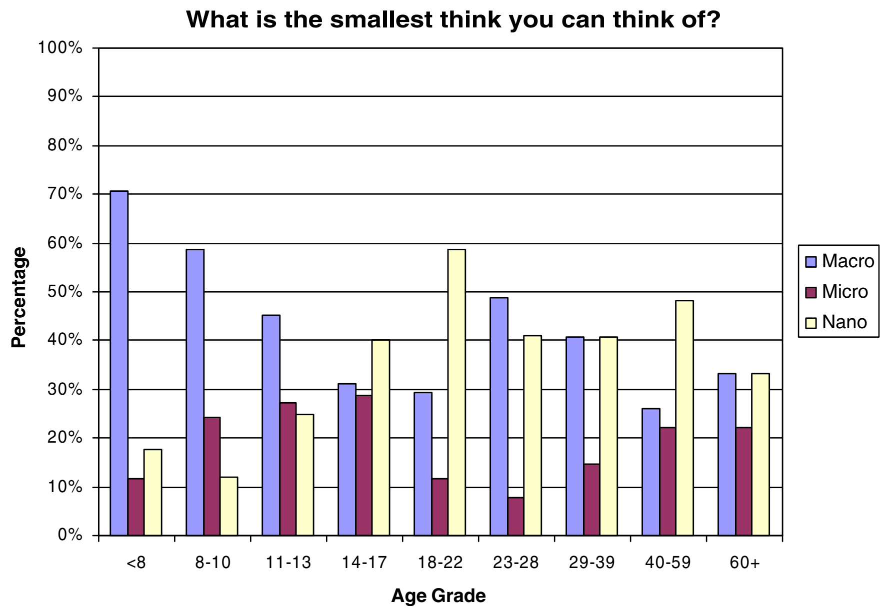

Figure 2. Responses of 1500 individuals to the question 'What is the smallest thing you can think of?'. Responses were categorized into three size scales: 'macro', 'micro' and 'nano'. All visible objects were coded as macroscopic. Sub-visible objects were divided into two classes, representing microscopic objects (e.g., cell, bacteria) and nanoscopic objects (e.g, proton, atom, molecule).

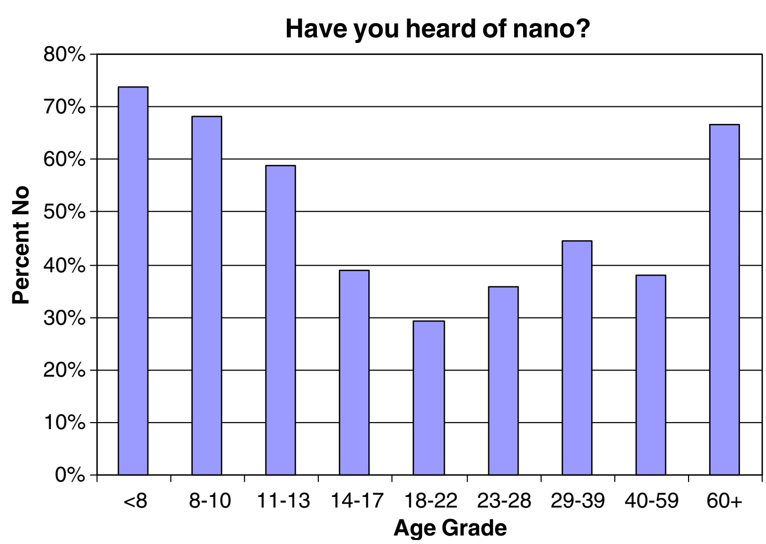

Figure 3. Percent of 1500 participants that responded 'no' to the question 'Have you heard of nano?'. The term 'nano' was unfamiliar to a majority of respondents across the age grades (60%). Those ages 18–22 were most familiar with the term at 71%.

define it. Responses from those age 29 and older varied. The majority (90%) did not know the term nanotechnology, and those who gave a correct or semi-correct answer said they learned about nanotechnology because they were avid readers, science enthusiasts, NPR listeners, or investors.

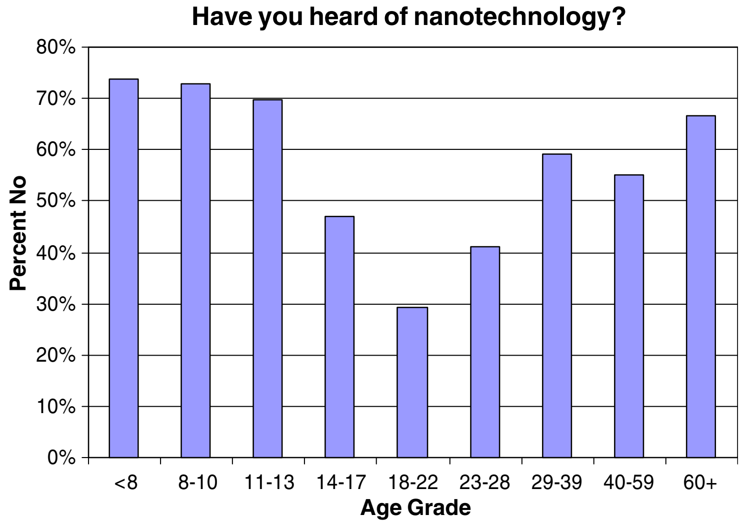

Figure 4. Percent of 1500 participants that responded 'no' to the question 'Have you heard of nanotechnology?'. The majority of respondents across age grades (90%) were unfamiliar with the term nanotechnology. Ages 18–22 were most familiar with the term at 71%.

One percent of the entire sample could correctly define the terms, with the correct definition for 'nano' being one-billionth (of a meter) and nanotechnology, the manipulation of matter at length scales of less than 100 nm. Most often when a semi-correct answer was given, nano was 'small' or 'really small'. Many thought nano an acronym, a Spanish word, or a term for grandmother. Nanotechnology was making tiny things, science, or a type of computer technology. Many respondents offered science fiction worthy definitions of 'robots', 'nanobots' and 'tiny cameras that are injected into your body' suggesting that their knowledge originates with popular fiction. Indeed many respondents who had heard of nanotechnology but could not recall its meaning offered that their knowledge was derived from fiction or television. The 'grey goo' scenario offered by the book *Prey* is one example of a popular conception of nanotechnology gone awry, and even proponents of the fictional side of nanotechnology admit that misconceptions exist in the public (Halford, 2004).

Individuals surveyed were also asked to place in the correct size order the units of measure 'millimeter', 'micrometer' and 'nanometer' and, in a separate question, the terms 'germ', 'molecule' and 'atom'. Respondents of all ages were more successful ordering units of measure than in putting 'germ', 'molecule' and 'atom' in correct size order. Up until age 11 children had difficulty putting both sets of terms in proper order. Children age 11 and older had more success than younger children in putting the three units of measure in correct size order. Only 15% of 11–13 years old could correctly order germ, molecule and atom. Adults also had trouble putting germ, molecule and atom in the appropriate size context. These findings match a 2002 national study of 500 people commissioned by the University of California which showed adults were only slightly more successful than youth in correctly ordering by size three sub-visible terms: 'cell', 'DNA', 'atom' (Spencer, 2003). Adults in the current study appeared to struggle with the same issues as children, a lack of understanding of relative scale and function of sub-visible objects.

The inability of most children up to age 13 to put 'millimeter', 'micrometer' and 'nanometer' in the correct order is not surprising. In New York State where 35% of the interviews were conducted, the term micro is not introduced until the eighth grade while the term nanometer is not part of the formal curriculum (NYSED, 2004). High school students learn about atoms and molecules, but the relative scale of these subvisible entities is not necessarily the focus of instruction (Driver et al., 1994). The failure of children and adults to correctly place in order the terms 'germ', 'molecule' and 'atom' suggests an inability to put these terms into proper context, that germs are made up of molecules and molecules in turn are made up of atoms. Whether this is truly a context issue or an uncertainty about the vocabulary on the part of the respondent is difficult to determine.

Discussion

The results of this study lay the groundwork for future exploration into the best methods for introducing the public to nanotechnology (Mehta, 2004). Nanotechnology is a complex topic that requires children and adults to accept that there is a world they cannot see and further, that scientists can manipulate atoms and molecules to create useful technologies. We need to better understand what the public knows about nanotechnology, how they came to know these things, and what avenues lead to the highest level of understanding. Without this understanding, the public will not be able to engage in the social and political debates that result from emerging technology. Enhancing the public understanding of nanotechnology will be an important challenge to avoid a backlash by a less than informed public (Pilarski et al., 2004). Lessons learned from other emerging technologies including biotechnology may suggest best methods for public engagement (Einsiedel & Goldenberg, 2004). One issue is simply the definition of nanotechnology and the drift of the term nanotechnology to include a broad number of technological advances (Drexler, 2004). Engaging the public is one means to affect an enhanced understanding but there are significant barriers to an accurate and meaningful dialogue (Mehta, 2004). While there appears to be a generally favorable attitude toward nanotechnology based upon previous surveys where attitude was probed, the exact nature of the public's enthusiasm is not obvious (Bainbridge, 2002; Cobb & Macoubrie, 2004; Dowling, 2004). Since most of the individuals surveyed in our study who had heard of nanotechnology owe their awareness to the popular press, the tenor of those items will contribute to any shift in favor or in opposition to nanotechnology.

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