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From enabling technology to applications: The evolution of risk perceptions about nanotechnology

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Public opinion research on nanotechnology has primarily focused on judgments of abstract risks and benefits, rather than attitudes toward specific applications. This approach will be less useful as nanotechnology morphs from a scientific breakthrough into an enabling technology whose impacts on people's lives come in the form of concrete applications in specific areas. This study examines the mental connections or associations US citizens have with nanotechnology (e.g. the extent to which people associate nanotechnology with the medical field, the military, consumer products, etc.), and how these associations moderate the influences of risk and benefit perceptions on attitudes toward nanotechnology. Our results suggest that the assumption that risk perceptions shape overall attitudes toward emerging technologies is simplistic. Rather, individuals who associate nanotech with particular areas of application, such as the medical field, take risk perceptions much more into account when forming attitudes than respondents who do not make these mental connections.

Keywords: heuristics, mental associations, nanotechnology, opinion formation, risk, science

1. Introduction

Recent research on nanotechnology attitudes has been concerned with understanding how the public perceives the risks and benefits of the technology. Primarily, risk and benefit perceptions of nanotechnology have been measured in abstract—as opposed to application-specific—terms. For instance, Cobb and Macoubrie (2004) examined risk and benefit perceptions by having respondents report whether the risks of nanotechnology would outweigh its benefits. This type of measurement, of course, was very useful when nano first emerged as an abstract idea on the public agenda, but it carries with it three notable problems (e.g., Lee et al., 2005).

First, responses may be biased based on what has been called "response order effects" (e.g., Schuman and Presser, 1981). Asking respondents first whether "the benefits outweigh the risks", followed by response options for "the risks outweighing the benefits," or "risks and benefits being about equal," for instance, is a much different question than one that offers the "risks outweighing the benefits" as the first response option. Specifically,

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research in survey methodology suggests that "the earlier in the list [or response options] an acceptable answer appears, the more popular it will be" (Tourangeau et al., 2000: 250) among respondents. Second, this form of measurement forces respondents to make subjective summative judgments about the relative importance of several risks and benefits. Such judgments, unfortunately, are often skewed, given people's tendency to remember unfavorable information about a topic better than favorable information (e.g., Gilovich, 1991). Third, nanotechnology has often been described as an enabling technology, similar to the Internet (Siegrist et al., 2007). This means that it has applications in many different subfields, with significantly different risk–benefit trade-offs attached to each of them (e.g., the medical field vs. military applications). Abstract measures of risk perceptions, unfortunately, cannot tap these distinctions.

A second way in which risk perceptions have been measured is by having respondents assess the various risks and benefits of nanotechnology across several areas. Then, the overall benefit perceptions are subtracted from the overall risk perceptions to create a risk vs. benefit measure that weighs aggregate responses on a series of potential risk and benefit areas against one another (for example see Lee et al., 2005). While an improvement on the previous measure, this appraisal is also limited in that it cannot tap potentially simultaneous influences of risks *and* benefits on overall evaluations of emerging technologies (e.g., Currall et al., 2006). By combining the responses into a single measure valuable information is lost, in terms both of the distinct influences of risk and benefit perceptions, and of perceptions in different content domains. Awareness of the specific areas where risk and benefit perceptions converge and diverge, as well as why they do so, is therefore crucial to a more granular understanding of how the public views nanotechnology.

In this study we therefore examine risk and benefit perceptions separately, and assess how they shape support and perceptions of usefulness for nanotechnology, across a number of concrete mental connections or associations that US citizens have with the technology. Before outlining this approach in greater detail, however, it is important to briefly touch upon the ongoing public debate about nanotechnology.

The nanotechnology debate

In the simplest terms, nanoscience is the science of phenomena at the nanoscale, 1–100 nanometers (each nanometer is one billionth of a meter) in size. To give a better understanding of this scale, the diameter of a human hair is approximately 20,000 nanometers wide. Nanotechnology is a rapidly evolving science, and federal funding for nanotechnology in the US has approximately quadrupled during the past eight years (National Nanotechnology Initiative, 2008). Although various applications of the technology are already available to consumers, nanotechnology is poised to have even more significant impacts on both the worldwide economy and science itself in the coming years and the worldwide market for nanotechnology-based products is expected to reach $3.1 trillion by 2015 (Katz, 2008). However, despite large investments in the technology and its seemingly unlimited potential in terms of medical, environmental and consumer product breakthroughs, controversy surrounds the industry.

Most importantly, nanotechnology has the potential to lead to environmental or new human health problems. For instance, fullerenes, composed of spherically arranged carbon atoms, are being examined for potentially damaging effects on fish, aquatic microorganisms, and human liver cells and DNA (Consumer Reports, 2007). More recently, carbon nanotubes have been linked to inflammation of human lungs and have been referred to as the new asbestos (e.g., Consumer Reports, 2007; Poland et al., 2008).

What the public knows and fears

Research on public opinion of nanotechnology has shown that the American public is largely uninformed about this emerging industry (Cobb and Macoubrie, 2004; Scheufele and Lewenstein, 2005; Pidgeon et al., 2008), and that levels of knowledge have remained absolutely static over the last few years[1] (Scheufele et al., 2009). This is a troubling finding given the calls for greater inclusion of citizens in scientific and risk decision making (see Irwin, 1995; Wynne, 1996; Irwin and Michael, 2003; Jasanoff, 2003; Brown, 2006). The lack of awareness and factual knowledge about nanotechnology, however, has not stopped citizens from forming opinions about the technology. Cobb and Macoubrie (2004) reported that four in ten Americans in their sample believed the benefits of nanotechnology would outweigh the negatives. Conversely, just over 22 percent felt the opposite, believing that nanotechnology would produce more risks than benefits.[2] In a subsequent study, Scheufele and Lewenstein (2005) compared perceptions among respondents who reported having been aware of nanotechnology before being interviewed to those among respondents who had been unaware. They found that 55 percent of all respondents who indicated that they were aware of the issue of nanotechnology expressed overall support for the technology, compared to only 28 percent of the unaware. Similarly, 49 percent of aware respondents supported increased financial support for nanotech research, compared to only 22 percent of the unaware group.

Several studies (e.g. Cobb and Macoubrie, 2004; Scheufele et al., 2007) have shown that these variations in general attitudes cannot entirely be explained by differing levels of knowledge, and are likely due to perceptions about the potential risks and benefits (Scheufele and Lewenstein, 2005). But how, specifically, is the American public forming opinions about nanotechnology? And, how are risk and benefit perceptions being separately evaluated by US citizens when making judgments about the technology overall?

2. How attitudes about emerging technologies are formed

So how are these attitudes being formed, even in the absence of information? In recent years there has been a shift in how scholars are thinking about how the public forms opinions of emerging technologies (Nisbet and Scheufele, 2007). Prior to this shift, there was a prevailing belief among many scientists in particular that the public was willing and able to seek out information about emerging technologies in order to develop informed and accurate opinions (Miller and Kimmel, 2001). This "scientific literacy model" is built on the notion that providing scientific information to the public will lead to increased levels of knowledge which in turn will increase support for science and lead to better decision making (Miller, 1998). Since then, however, the scientific literacy model has been criticized as a "deficit model" (Wynne, 1991) that unfairly characterizes the public as "deficient" while portraying science as "sufficient" (Sturgis and Allum, 2004). Still others have argued that the "scientific literacy model" is too simplistic and that people can be described more accurately as "cognitive misers" or "satisficers" (Fiske and Taylor, 1991), who minimize their efforts related to information seeking and processing, and instead rely on a series of heuristic cues when making decisions about science and other ambiguous stimuli (Scheufele, 2006).

Heuristic cues

As outlined earlier, the mental associations people have when it comes to nanotechnology are potentially among the most important cues that shape opinion formation. When referring to nanotechnology associations in this context, we mean the types of thoughts or applications that come to mind when people are asked to think about nanotech. As an example, it has been suggested that people rely on "habitualized schemas" to interpret and evaluate their surrounding environment (Bourdieu, 1977), and in a recent study, Burri (2009) found that citizens turned to analogies and personal experiences in order to make sense of uncertain nanotechnology information. In their study examining opinions of biomedicine, Felt et al. (2008) noted that the specific features of a technology and how the public perceives those features can play a large role in shaping how the public views issues such as governance of a technology and public participation. As part of their conclusion they argue for a more "technology-sensitive" approach to issues of public participation. Furthermore, as Slovic et al. (2004) explain, people comprehend risk through an "experiential system" that relies on linkages between associations garnered through experience and emotional responses. In other words, individuals conform their risk assessments based on quick emotional appraisals (Kahan, 2008).

Given the role that nanotechnology plays as an enabling technology, the mental associations one has with the technology can play a potentially powerful role in shaping how risk and benefit information is utilized when forming opinions. These associations may be to the medical field, the military, or possibly, to tiny self-replicating robots. While some of these associations may point to the benefits of the technology, others may make salient a wide variety of risk factors and this can have huge implications for how individuals form opinions about the technology.

This study explores the extent to which risk and benefit perceptions interact with domain-specific associations in shaping attitudes toward nanotechnology. But before formulating more concrete hypotheses for these relationships, it is critical to understand these relationships in the context of other influences on public opinion, as identified in previous research.

Value predispositions and opinion formation

It has been demonstrated that value predispositions can play a large role in shaping opinions toward emerging technologies, with individuals being more likely to select information in a biased fashion to match their cultural and political dispositions (Kahan et al., 2009). Examining people's ideological values and religious beliefs as potential influences on public opinion, previous research has found a direct and negative effect between strength of religious beliefs and support for nanotechnology funding (Brossard et al., 2009). Based on this information the following hypothesis is proposed:

> *Hypothesis 1*: Religious guidance will be negatively related to support for nanotechnology, as well as beliefs in the usefulness of the technology

As of yet it appears as though neither the Democrats nor the Republicans have taken a particular side of the nanotechnology debate. Despite a 2006 pledge by former President Bush to double federal funding in the basic research programs of the physical sciences over the next 10 years (CQ Transcriptions, 2006), there appear to be no discernible partisan motives behind the push for increased nanotechnology funding. We therefore pose the following research question:

> *Research Question 1*: What influence will ideology have on support for nanotechnology, as well as beliefs in the usefulness of the technology?

News media and opinion formation

Beyond predispositional factors, news media have been shown to play a key role in shaping public perception of nanotechnology (e.g., Scheufele and Lewenstein, 2005; Brossard et al., 2009). Given the relative unfamiliarity with nanotechnology among the general public, media continue to serve as an important information source to lay audiences. And much of the news coverage, so far, has been positive (Friedman and Egolf, 2005; Stephens, 2005). Consistent with these analyses of news coverage, Brossard et al. (2009) found that both science newspaper attention and use and science television attention and use had a positive effect on public attitudes toward funding of nanotechnology. Based on this information the following hypothesis is proposed:

Hypothesis 2: Science media use will be positively related to support for nanotechnology, as well as beliefs in the usefulness of the technology

Knowledge and opinion formation

As alluded to earlier, there is a widespread belief that as the public gathers scientific knowledge about a technology, their risk judgments become more accurate and better aligned with experts', and their attitudes towards the technology will become more positive (Ho et al., 2008). While some research has supported this claim (see Miller and Kimmel, 2001), the overall picture can best be described as mixed. Recent research on nanotechnology has followed a similar pattern of mixed results. Lee et al. (2005) found no direct effects for nanotechnology knowledge on levels of support, while Cobb and Macoubrie (2004) found that respondents with greater knowledge of nanotechnology were more likely to believe that the benefits would exceed the risks and less likely to believe that the risks would exceed the benefits. Based on the inconclusive findings of these studies the following research question is proposed:

Research Question 2: How will nanotechnology knowledge relate to support and beliefs about the usefulness of the technology?

Risk and benefit perceptions and opinion formation

Not surprisingly, risk and benefit perceptions can have major influences on the acceptance or rejections of a technology. Among others, Ferber (1999), Sjöberg (2004), and Gaskell et al. (1999) have noted that perceptions of risk associated with genetically modified foods, for example, adversely affected sales and lessened worldwide demand. Additionally, Olofsson et al. (2006) demonstrated that decreased perceptions of risk toward stem cell research led to a greater acceptance of the research. In short, increased perceptions of benefits associated with a technology have been shown to increase acceptance of the technology, while increased perceptions of risks have been found to lessen public acceptance (Siegrist, 2000; Olofsson et al., 2006). With this information in mind, the following hypotheses are proposed:

Hypothesis 3a: Risk perceptions will be negatively related to support for nanotechnology, as well as beliefs in the usefulness of the technology

Hypothesis 3b: Benefit perceptions will be positively related to support for nanotechnology, as well as beliefs in the usefulness of the technology

Nanotechnology associations and opinion formation

Little is known about what types of products or fields of study people associate nanotechnology with, nor how these associations can impact benefit and risk perceptions. However, research suggests that the specific features of a technology (Felt et al., 2008), or possibly, the mental associations citizens have to nanotech, are likely to shape overall evaluations of the technology. Research on priming (Iyengar and Kinder, 1987; Scheufele, 2000; Scheufele and Tewksbury, 2007), for instance, has shown that people's evaluation of candidates or issues can be influenced by the considerations that are most salient at the time of decision making. This perspective implies that individuals do not rely on all relevant information when forming decisions, and instead, are susceptible to "accessibility biases" (Iyengar, 1990) and over-sample from the information that can be most easily retrieved from memory at the time of decision making (Iyengar, 1990). Moreover, Nisbett and Ross (1980) have provided evidence for a "vividness bias," i.e., the notion that people give "inferential weight to information in proportion to its vividness" (p. 62) or prominence. Although evidence for a vividness bias is mixed, Iyengar and Kinder (1987) note that there is strong evidence for the bias when "vividness is defined as the contrast between personalized, case history information and abstract statistical information" (p. 35).

Additionally, recent research in "exemplification" (Brosius and Bathelt, 1994; Zillmann, 2006) has provided further evidence for the differential weighting of exemplary and base rate information. In particular, vivid or dramatic examples often lead audiences to ignore accurate and fact-based baseline information when evaluating the probability of a risk or other occurrence. For example, Zillmann et al. (1992, as cited in Gibson and Zillmann, 1994) found that exposure to vivid exemplars caused subjects to overestimate the likelihood of people regaining weight following a diet. In another example, Gibson and Zillmann (1994) found that respondents exposed to extremely distorted exemplars were more likely to consider carjacking a serious national problem than those respondents exposed to less distorted exemplars, and that this effect can increase over time.

This is not to say that exemplars serve as simple, unidirectional cues for shaping attitudes. In fact, these associations or exemplars could be triggering both positive and negative opinions regarding nanotechnology. For example, many people may associate nanotechnology with exemplar applications from the medical field, with some of those respondents thinking about medical breakthroughs made possible by nanotechnology, and others thinking about potentially hazardous nanotoxins. With that in mind, the following research question is proposed:

Research Question 3: How will nanotechnology associations relate to support and beliefs about the usefulness of the technology?

Based on the theoretical assumptions underlying spreading activation and vividness, we also hypothesize that these mental associations play an important role in influencing how people translate their perceptions of the risks and benefits related to nanotechnology into general attitudes about the technology. In particular, concrete and vivid applications of a technology are likely to serve as important primes when people try to translate their risk/benefit perceptions into general attitudes toward the technology. Being aware of particular applications of nanotechnology, for instance, also activates related nodes and constructs in respondents' brains (Collins and Loftus, 1975), which then become the basis for subsequent judgments, such as translating risk and benefits perceptions into general attitudes toward nanotechnology.[3] In short, risk and benefit perceptions may influence attitudes differently when people associate nanotechnology with issues related to human health, as is likely the case for associations to the medical field, than when they associate it with leisure activities, as is likely the case for those associating it with sporting equipment. Based on this reasoning the following hypothesis is set forth:

Hypothesis 4: Mental associations will moderate the effect of risk and benefit perceptions on support and usefulness of nanotechnology

3. Methodology

In order to test these predictions and answer our research questions, we relied on data from a nationally representative random-digit-dial telephone survey[4] with 1,015 US adults aged 18 years and older. The survey was conducted by the University of Wisconsin Survey Center between May and July of 2007 using a dual frame sampling method, combining national random-digit-dial and listed household samples. The final sample size was 1,015, with a response rate of 30.60%, calculated using AAPOR's (2008) formula for RR3. Given low levels of familiarity with nanotechnology among our target population, we tried to minimize non-response bias by devoting significant resources to additional call backs and refusal conversations. Finally, items within matrix-type blocks of questions (e.g. the "associations" block) were randomized to avoid possible question order effects.

Measures

Age, gender, and education served as control variables. *Age* was measured as a continuous variable ($M = 55.3$, $SD = 16.4$).[5] *Gender* was a dichotomous variable with female coded as "0" and male coded as "1" (47.6 percent males). *Education* was an ordinal variable measured with eight categories. The categories ranged from "never attended school or only attended kindergarten" (coded as "1") to "graduate degree" (coded as "8"). The sample median was "5," indicating "college one year to three years (some college or technical school)" ($SD = 1.47$).

Ideology was measured using seven categories ranging from "very liberal" (coded as "1") to "very conservative" (coded as "7") on both economic issues ($M = 4.5$, $SD = 1.5$) and social issues ($M = 4.2$, $SD = 1.7$). These variables were then averaged to create a total ideology score ($M = 4.4$, $SD = 1.4$, $r = .59$). *Religiosity* was measured by asking respondents, "How much guidance does religion play in your everyday life?" using a 10-point scale. The scale was anchored at "No guidance at all" (coded as "1") to "A great deal of guidance" (coded as "10"; $M = 6.7$, $SD = 2.9$).

Attention to science in the media was made up of attention to science news in newspapers, online, and on television. *Attention to science in newspapers* was measured using an 11-point scale (0 = "No attention at all," 10 = "Very close attention") asking respondents how much attention they pay to the following types of stories when reading the newspaper: "Stories related to science and technology," "Stories about scientific studies in new areas of research such as nanotechnology," and "Stories about the social or ethical implications of emerging technologies." The three items were averaged to form an index with scores ranging from "0" to "10" ($M = 4.6$, $SD = 2.8$). Cronbach's alpha was .94.

Attention to science online was measured using an 11-point scale (0 = "No attention at all," 10 = "Very close attention") asking respondents how much attention they pay to the following types of news and information on the Internet: "Content related to science and technology," "Content related to specific scientific developments, such as nanotechnology," and "Content related to the social or ethical implications of emerging technologies." The three items were averaged to form an index with scores ranging from "0" to "10" ($M = 3.3$, $SD = 2.95$). Cronbach's alpha was .94.

Attention to science on television was measured using an 11-point scale (0 = "No attention at all," 10 = "Very close attention") asking respondents how much attention they pay to the following types of content on television: "Science and technology," "Specific scientific developments, such as nanotechnology," and "Information about the social or ethical implications of emerging technologies." The three items were averaged to form an index with scores ranging from "0" to "10" ($M = 5.3$, $SD = 2.3$). Cronbach's alpha was .90.

Knowledge of nanotechnology was measured using the following six true–false items ("1" = true, "0" = false): (a) "Nanotechnology involves materials that are not visible to the naked eye," (b) "U.S. corporations are NOT using nanotechnology yet to make products," (c) "Experts consider nanotechnology to be the next industrial revolution," (d) "A nanometer is a billionth of a meter," (e) "Nanotechnology allows scientists to arrange molecules in ways that do NOT occur in nature," and (f) "A nanometer is about the size of an atom." An additive index, with scores ranging from "0" to "6" was created from these six measures (M = 3.9, SD = 1.4). The index had a KR-20 of .49.

Overall measures of risk and benefit perceptions for nanotechnology were also created. *Risks* was measured using a 10-point scale (1 = "Do not agree at all," 10 = "Agree very much") asking respondents how much they agree with a set of seven risk statements related to nanotechnology. Respondents were asked how much they agree that "Nanotech may lead to the loss of personal privacy because of tiny new surveillance devices," "Nanotech may lead to an arms race between the U.S. and other countries," "Nanotech may lead to new human health problems," "Nanotech may be used by terrorists against the U.S.," "Nanotech may lead to the uncontrollable spread of very tiny self-replicating robots," "Nanotech may lead to more pollution and environmental contamination," and "Because of nanotech we may lose more U.S. jobs." The seven items were averaged together to form an index with scores ranging from "0" to "10" (M = 5.0, SD = 1.8) with Cronbach's alpha of .82.

Benefits was measured using a 10-point scale (1 = "Do not agree at all," 10 = "Agree very much") asking respondents how much they agree with a set of seven benefit statements related to nanotechnology. Respondents were asked how much they agree that "Nanotech may lead to new and better ways to treat and detect human diseases," "Nanotech may lead to new and better ways to clean up the environment," "Nanotech may give scientists the ability to improve human physical and mental capabilities," "Nanotech may help us develop increased national security and defensive capabilities," "Nanotech may lead to technologies that will help solve our energy problems," "Nanotech may revolutionize the computer industry," and "Nanotech may lead to a new economic boom." The seven items were averaged together to form an index with scores ranging from "0" to "10" (M = 6.5, SD = 1.9) with Cronbach's alpha of .91.

Each of the nanotechnology associations was measured with a single dichotomous question (yes coded as "1"; no coded as "0") asking respondents if they associate nanotech with each of the following areas of nanotechnology research and development: *Consumer products* (e.g. nano-based sunscreens and bath towels), *Sports equipment* (e.g. nano-based tennis rackets and golf clubs), *Military and defense* (e.g. "smart weapons" made with nanotechnology), *Surveillance and privacy* (e.g. tiny surveillance cameras), *Machines and computers* (e.g. production of faster and more advanced machines and computers), the *Environment and energy* (e.g. solar panels, batteries, and hydrogen fuel cells made using nanotechnology), the *Medical field* (e.g. products such as SilvaGard which use silver nanoparticles), and the *Biological engineering of humans* (e.g. nanotechnology's role in enhancing the efficiency of bacteria as delivery systems in the human body).

The dependent variables of interest for this study were designed to tap people's overall judgments about nanotechnology. This included general support for nanotechnology and beliefs about the usefulness of the technology. *Support for nanotechnology* was measured using a 10-point scale (1 = "Do not agree at all," 10 = "Agree very much") asking respondents their level of agreement with the following statement: "Overall, I support the use of nanotechnology" (M = 6.2, SD = 2.5). *Nanotechnology's usefulness* was measured using the same 10-point scale (1 = "Do not agree at all," 10 = "Agree very much") asking respondents how much they agree with the following statement: "Nanotechnology is useful for society" (M = 6.4, SD = 2.4).

Methodological notes

We tested our hypotheses and research questions using hierarchical ordinary least squares regression models (Cohen and Cohen, 1983), entering independent variables into the regression based on their assumed causal order. The first block consisted of the demographic variables age, gender and education. In the second block religious guidance and ideology were entered. This predisposition block was followed by a science news media use block, a knowledge block, a risk/benefit perception block, and the mental associations block.

The final block of the regression consisted of interaction terms. These interaction terms were created by multiplying the centered values of the main effects variables. This was done to avoid issues of multicollinearity between the interaction term and its components (Cohen and Cohen, 1983). These interactions were between each of the mental associations (8 in total) and both risk and benefit perceptions, resulting in a total of 16 interaction terms.

Hierarchical regression models also provide estimates of each of the blocks entered. After the first block, incremental R-square estimates indicate the amount of variance that is accounted for by variables in additional blocks, after all other variables in the model have been accounted for.

4. Results

As Table 1 shows, males and more educated respondents were more likely to express support for nanotechnology. And as Table 2 illustrates, more educated respondents were more likely to express beliefs in the usefulness of nanotechnology, however, gender did not attain significance as in the previous regression. In total, demographics explained 10.7% and 8.5% of the variance for *Support for nanotechnology* and *Nanotechnology's usefulness*, respectively.

Among the value predispositions, religiosity was negatively and significantly related to perceptions of the usefulness of the technology. Interestingly, religiosity did not have any significant influence on support for nanotechnology. Thus, there is partial support for *H1*. The first research question deals with the influence of ideology on support and perceptions of usefulness of nanotechnology. In response to *RQ1*, ideology emerged as a significant negative predictor in only one of the regressions. More concretely, liberals were more likely than conservatives to express support for nanotechnology. However, the same effects did not emerge when usefulness was the dependent variable. In total, value predispositions explained an additional 4.1% of the variance for each of the two models.

Once all other variables were controlled for, media use had very limited impacts on each of the dependent variables. In fact, only *Attention to science on TV* remained a significant predictor into the final model for either of the two regressions, while *Attention to science news online* and *Attention to science news in newspapers* failed to maintain significance into either of the final models. More concretely, the more attention Americans pay to science news on television the more likely they are to express support for nanotechnology. The same effects of media were not seen for beliefs about the usefulness of the technology. Therefore, there is rather limited support for *H2*. Nonetheless, media use accounted for an additional 9.4% and 6.0% of the variance in support for nanotechnology and the usefulness of nanotechnology, respectively.

The fourth block of the regression looked at the role of knowledge in forming opinions about nanotechnology. For the regression examining support for nanotechnology and in partial response to *RQ2*, knowledge emerged as a significant and positive predictor of support.

Table 1. Regression predicting support for nanotechnology

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Block 1: Demographics							
Education	.23***	.21***	.12***	.12***	.07**	.06*	.06*
Sex (Male = 1)	.17***	.16***	.13***	.13***	.09***	.09**	.08**
Age	–.11***	–.07*	–.06*	–.04	–.03	–.02	–.02
Inc. R^2 (%)	*10.7****						
Block 2: Value Predispositions							
Ideology (Cons. = 1)		–.14***	–.12***	–.11**	–.06*	–.07*	–.06*
Religiosity		–.11**	–.11**	–.10**	–.05	–.04	–.04
Inc. R^2 (%)		*4.1****					
Block 3: Media Use							
Attn to science in newspapers			.02	.00	.02	.01	.01
Attn to science on web			.14***	.11**	.06	.06	.06
Attn to science on TV			.23***	.23***	.08*	.08*	.08*
Inc. R^2 (%)			*9.4****				
Block 4: Knowledge							
Nanotech knowledge				.16***	.07**	.07*	.06*
Inc. R^2 (%)				*2.5****			
Block 5: Perceptions							
Risks					–.20***	–.20***	–.20***
Benefits					.59***	.59***	.58***
Inc. R^2 (%)					*24.8****		
Block 6: Associations							
Sports						–.02	–.02
Military						.03	.05
Products						.00	.00
Medicine						.02	.00
Bioengineering						–.01	–.01
Environment						–.06*	–.06*
Machines						.02	.01
Privacy						.03	.02
Inc. R^2 (%)						*0.6*	
Block 7: Interactions							
Risks × Sports							–.03
Benefits × Sports							–.02
Risks × Military							.01
Benefits × Military							–.01
Risks × Products							–.04
Benefits × Products							–.03
Risks × Medicine							–.06*
Benefits × Medicine							–.05
Risks × Bioengineering							–.06*
Benefits × Bioengineering							–.02
Risks × Environment							.01
Benefits × Environment							–.02
Risks × Machines							–.05*
Benefits × Machines							–.05*
Risks × Privacy							–.03
Benefits × Privacy							–.00
Inc. R^2 (%)							*1.3*
Total R^2 (%)							53.3

Notes: $*p < .05$, $**p < .01$, $***p < .001$.
Cell entries for all models are standardized regression coefficients for Blocks 1, 2, 3, 4, 5, and 6 while cell entries are before-entry standardized regression coefficients for Block 7.

Table 2. Regression predicting nanotechnology's usefulness

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Block 1: Demographics							
Education	.20***	.18***	.12**	.11**	.08**	.07*	.06*
Sex (Male = 1)	.14***	.11**	.10**	.10**	.05*	.06*	.05
Age	–.12*	–.08*	–.07*	–.05	–.04	–.02	–.03
Inc. R^2 (%)	*8.5****						
Block 2: Value Predispositions							
Ideology (Cons. = 1)		–.11**	–.09**	–.08*	–.04	–.04	–.04
Religiosity		–.14***	–.14***	–.13***	–.09**	–.08**	–.09**
Inc. R^2 (%)		*4.1****					
Block 3: Media Use							
Attn to science in newspapers			–.03	–.04	–.02	–.03	–.02
Attn to science on web			.11**	.09*	.03	.03	.03
Attn to science on TV			.20***	.20***	.05	.05	.04
Inc. R^2 (%)			*6.0****				
Block 4: Knowledge							
Nanotech knowledge				.15***	.05	.04	.04
Inc. R^2 (%)				*2.2****			
Block 5: Perceptions							
Risks					–.15***	–.15***	–.16***
Benefits					.62***	.61***	.59***
Inc. R^2 (%)					*27.1****		
Block 6: Associations							
Sports						.01	.01
Military						–.03	–.03
Products						.04	.04
Medicine						.04	.03
Bioengineering						.01	.00
Environment						–.07*	–.07*
Machines						.04	.03
Privacy						.03	.03
Inc. R^2 (%)						*0.9*	
Block 7: Interactions							
Risks × Sports							.01
Benefits × Sports							–.03
Risks × Military							–.02
Benefits × Military							–.03
Risks × Products							–.02
Benefits × Products							–.04
Risks × Medicine							–.07**
Benefits × Medicine							–.05
Risks × Bioengineering							–.04
Benefits × Bioengineering							–.05
Risks × Environment							.02
Benefits × Environment							–.03
Risks × Machines							–.06*
Benefits × Machines							–.06*
Risks × Privacy							–.02
Benefits × Privacy							–.05
Inc. R^2 (%)							*1.0*
Total R^2 (%)							49.7

Notes: *$p < .05$, **$p < .01$, ***$p < .001$.
Cell entries for all models are standardized regression coefficients for Blocks 1, 2, 3, 4, 5, and 6 while cell entries are before-entry standardized regression coefficients for Block 7.

However, knowledge of nanotechnology did not significantly impact perceptions of nanotech's usefulness. Across the two dependent variables nanotechnology knowledge accounted for a small, but statistically significant portion of the overall variance. For support it accounted for 2.5% of the variance and for usefulness it accounted for an additional 2.2% of the variance.

Next, risk and benefit perceptions were entered as a block in the regression. As expected, risk and benefit perceptions played a large role in influencing each of the dependent variables. Across the regressions risk perceptions had a strong negative relationship with the dependent variable while benefit perceptions had an even stronger positive relationship with the dependent variable. In other words, as perceptions of risks associated with nanotechnology increase, support for the industry, as well as beliefs in its usefulness, decrease. On the other hand, as nanotechnology benefit perceptions increase so too does support for the industry as well as beliefs in its usefulness. Thus, there appears to be strong support for *H3a* and *H3b*. However, this support is not as clear cut as it seems and this complexity will be discussed at a later point in this paper. Across the two regressions, risk and benefit perceptions accounted for the largest portion of explained variance. This block accounted for 24.8% of the variance in support and 27.1% in usefulness.

The last block prior to the interactions examined the cognitive associations that people have with nanotechnology. Figure 1 shows the percentage of respondents associating nanotechnology with each of the eight areas of interest. In response to *RQ3*, in each regression only one of the association variables emerged as having a significant relationship with the dependent variable. In both the first and second regression models, associating nanotechnology with the environment had a negative impact on the dependent variable. More concretely, the more an individual associates nanotechnology with the environment the less likely that

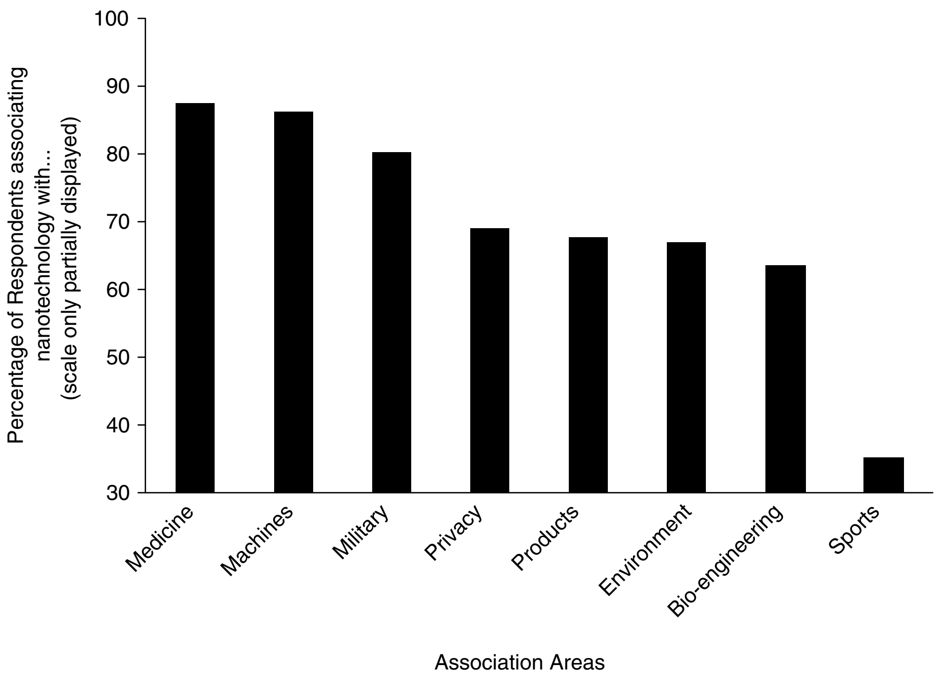

Figure 1. Mental associations for nanotechnology.

individual is to support nanotechnology and view it as useful for society. The cognitive associations block accounted for an additional 0.6% of the explained variance in support for nanotechnology and an additional 0.9% in the usefulness of the technology. However, in each case the amount of explained variance did not attain statistical significance.

H4 hypothesized that cognitive associations will moderate the effect of risk and benefit perceptions on support and usefulness of nanotechnology. In total, four separate interactions emerged as significant in the regression predicting support, while an additional three interactions were significant when usefulness was the dependent variable. Figure 2 depicts the significant interactions when support for nanotechnology is the dependent variable. As illustrated in Figure 2, the influence of risk perceptions on support for nanotechnology is much stronger for those associating nanotech with the medical field. In particular, individuals associating nanotechnology with the medical field tend to have high levels of support when risk perceptions are low, but their support drops sharply as their risk perceptions increase. For those not associating nanotechnology with the medical field a much less pronounced drop in support occurs as risk perceptions move from low to high. Figure 2 also depicts a similar pattern for the moderating effects of associating nanotechnology with the biological engineering of humans, and for those associating nanotechnology with machines and computers.

This pattern can also be seen when perceptions of the usefulness of nanotechnology is the dependent variable. For instance, Figure 3 shows that those associating nanotechnology with either the medical field or machines and computers have quite large drops in beliefs about its usefulness as risk perceptions increase. In contrast, those who do not associate nanotechnology with these two areas vary little in their beliefs about nanotech's usefulness based on risk perceptions.

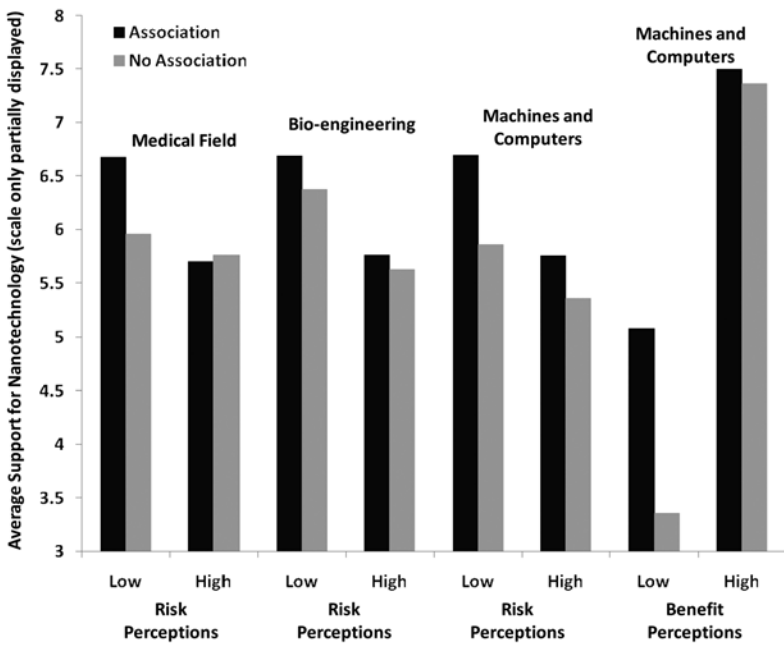

Figure 2. Risk and benefit perceptions, cognitive associations, and average support for nanotechnology.

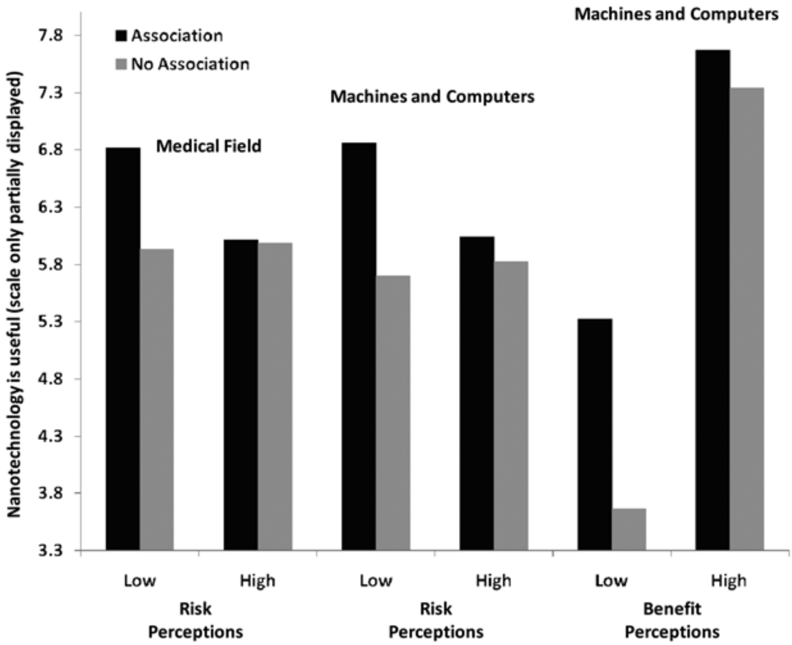

Figure 3. Risk and benefit perceptions, cognitive associations, and belief in the usefulness of nanotechnology.

Figures 2 and 3 also provide an example of the way in which associations can moderate the influence of benefit perceptions on support for nanotechnology. In Figure 2, the influence of benefit perceptions on support for nanotechnology is much weaker for those associating nanotech with the machines and computers. In particular, individuals who do not associate nanotechnology with the machines and computers tend to have much more pronounced jumps in support as their benefit perceptions increase, while those who do associate the technology with machines and computers tend to have less impressive leaps in support as benefit perceptions increase. Figure 3 shows essentially the same pattern when the usefulness of nanotechnology is the dependent variable. Based on these results, there is support for *H4*.

In total, the regressions explained over 45% of the variance in each of the dependent variables. In particular, when *Support for nanotechnology* was the dependent variable, 53.3% of the variance was explained by the model. And, when *Nanotechnology's usefulness* was the dependent variable, this model was able to explain 49.7% of the variance.

5. Discussion

This study examined the influence of value predispositions, news media use, knowledge, risk and benefit perceptions, and nanotechnology associations on support for, and beliefs in the usefulness of nanotech. First, this study provides some further evidence for the importance of demographic factors and value predispositions on public opinion of nanotechnology. Education emerged as a significant and positive predictor in each of the regressions, and there was some evidence that males, liberals, and the less religious have more positive attitudes toward the technology. Surprisingly, attention to science in the media proved to have only limited impacts on nanotech attitudes, while there was some support for the positive impact of knowledge on nanotechnology attitudes. There was also some limited support for the direct influence of mental associations on attitudes toward nanotech and strong support for the influence of risk and benefit perceptions on opinions regarding the technology. Most importantly, however, our study shows a moderating role of people's mental associations with nanotechnology on the influence of risk and benefit perceptions on general attitudes toward the technology. These findings suggest that the influence of risk and benefit perceptions on public attitudes toward nanotechnology is more complicated than previously thought and that the types of associations people have with nanotechnology can influence how people utilize their perceptions of risks and benefits when forming opinions about the technology.

As with any research, this study carries with it several limitations. The first concern is related to levels of measurement at various stages of our model. The nanotechnology association variables are dichotomous measures rather than continuous Likert-type scales, for example. This is problematic because these dichotomous measures limit the amount of variance among responses and provide no context for how strongly individuals associate nanotechnology with each of the different areas. Additionally, the dependent variables in our regression were single-item measures which make it impossible to assess or control for random measurement error.

Furthermore, we measured respondents' knowledge of nanotechnology with a series of true or false questions. While this form of measurement had clear advantages in terms of ease of administration in phone surveys, it only captures a somewhat narrow subdimension of public levels of information. In interpreting our results, it is therefore important to keep in mind that our measures do *not* capture a more abstract and in-depth understanding of the issue of nanotechnology, similar to what researchers have called cognitive complexity (Bieri, 1955), sophistication (e.g., Luskin, 1987) or integrated thinking (Neuman, 1981), or localized and environment-specific knowledge that is often critical in explaining individual risk judgments and attitudes (e.g., Wynne, 1992).

A final problem relates to the issue of causality. As mentioned earlier, research has shown that the considerations that are the most salient can have strong implications for how an individual evaluates issues (Iyengar and Kinder, 1987; Scheufele, 2000; Scheufele and Tewksbury, 2007). Based on our results it appears likely that the associations that are most salient in people's minds shape how they interpret potential risks or benefits when asked to form general judgments about nanotechnology. Unfortunately, because we are dealing with cross-sectional data we cannot be sure that this is the actual causal order. It may be that this process operates in a different direction, although this seems unlikely.

With these considerations in mind, this study provides useful information regarding how people arrive at opinions regarding nanotechnology. Consistent with previous research, religiosity had a negative impact on opinions for nanotech, although, this effect only emerged when usefulness was the dependent variable. However, contrary to previous research, media use played a relatively small role in predicting attitudes. Specifically, attention to television science news was positively related to support for nanotechnology, but all other science media attention variables failed to achieve significance into the final models for either of the two dependent variables.

This pattern is particularly interesting, given the abundance of nano-related information available to citizens online (in comparison to television, for example) and the ease of retrieving this information. This creates an interesting paradox, given that audiences still seem to seek nano-related information predominantly in traditional news channels. Our data, for instance, suggested that citizens are paying less attention to online science news ($M = 3.3$) than television science news ($M = 5.5$). As nano audiences increasingly move online (Anderson et al., 2009), it will therefore be interesting to assess the impact of these potentially information-rich online news environments on public attitudes and beliefs.

Importantly, associating nanotechnology with the environment emerged as having a negative relationship with both support and beliefs in the usefulness of the technology. This suggests that when nanotech is being linked with the environment it is likely in terms of pollution or some other form of environmental hazard that is negatively impacting support. This link is particularly noteworthy, given recent findings that suggest that environmental pollution was one of only two areas for which leading US nano researchers saw a higher potential for risks than the general population (Scheufele et al., 2007). It will be interesting for future research to further explore the opinion dynamics that will result from the public developing a better understanding of expert consensus on the potential risks of nanomaterials.

However, the most important contribution of this study is in showing the moderating role of nanotechnology associations on the risk and benefit perception–attitude link. This study clearly indicates the important role that nanotechnology associations can have in subsequent opinion formation. In particular, this study demonstrates that individuals associating nanotechnology with the medical field, the biological engineering of humans, as well as with machines and computers tend to have positive opinions when risk perceptions are low, but that these opinions can quickly change as risk perceptions increase. This suggests a group of people who are more likely to base decisions about support and the technology's usefulness on risk and benefit perceptions. In contrast, those who do not associate nanotechnology with any of those three areas have much more stable opinions, and these opinions oftentimes tend to be less positive than the previous group's, even when risk perceptions are deemed low.

It is also important to note that nanotechnology associations did not just moderate the influence of risk perceptions on opinion formation. The influence of benefit perceptions on opinions was also dependent on one of the association variables. When looking at both support for nanotech as well as beliefs in its general usefulness, associating the technology with machines and computers moderated the influence of benefit perceptions on attitudes. This time, however, those who did not associate nanotechnology with machines and computers tended to have the more stable attitudes, while those who did associate nanotechnology with machines and computers tended to follow benefit perceptions closely when forming attitudes about the technology.

Although the present research does not allow for an understanding of why associations to only a few particular areas impact how risk and benefit perceptions are utilized, a few educated guesses are possible. The reliance on risk perceptions for those associating nanotechnology with the medical field and the biological engineering of people seems to make sense given the nature of the associations. Both the medical field and the biological engineering of humans can be said to fall under the larger umbrella of human health. Associations to these health fields are likely to prime individuals to think of the technology in a more personal manner, in particular, as it relates to their own health, or possibly, the health of loved ones. Those thinking in such personal terms may be more likely to carefully follow risk perception information when forming opinions owing to the seriousness of the issue, while those not making the same associations would not have the same motivation to closely follow risk perceptions. Importantly, a major medical breakthrough or revelation about a health risk is likely to have a great impact on how the public thinks about the technology as well as how they will use their risk and benefit perceptions when forming attitudes about the technology.

The importance of associations with machines and computers is also open to interpretation. It is possible, for instance, that more technophile respondents are also more likely to associate nanotechnology with machines and computers. These technophile respondents are likely to be extremely interested in matters of science and technology, more generally, and are therefore likely to also have favorable attitudes toward nanotech. This may lead to a ceiling effect where increased benefit perceptions are unlikely to positively impact attitudes for technophiles, but will have a significant positive impact for less technology-friendly respondents who also do not associate nanotechnology with machines and computers.

Future research will need to explore some of these interactions of associations, risks, and attitudes in greater detail. We have offered some tentative explanations for why associations with these particular areas (the medical field, the biological engineering of humans, and machines and computers) may have influenced how risk and benefit perceptions are utilized, but future research should test these guesses empirically. It may also prove helpful to gain an understanding of where these associations begin and how they are formed amongst the public.

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Notes

1 Of course, scholars have criticized the belief that scientific knowledge can be accurately measured through surveys. For example, Wynne (1991) points to the now common viewpoint in sociology of science that there fails to be a clear consensus, even among scientists themselves, as to what constitutes scientific knowledge in any given context. However, Sturgis and Allum (2004) note the value in factual knowledge measures, contending that these measures act as diagnostic indicators of greater information levels.

2 These findings do not appear to be isolated to the US. On the basis of their results from four deliberative workshops in the US and the UK, Pidgeon et al. (2008) noted that there were more similarities than differences between US and UK respondents in areas of risk and benefit perceptions for nanotechnology.

3 Of course, as Joseph Dumit (2004) has argued, processes in the brain are not nearly as simple as some of these cognitive models make it appear.

4 It is important to note that influences on attitudes are a function of several factors, including social, institutional and individual variables. For example, Scheufele et al. (2009) found that country-level variables can have large impacts on attitudes toward nanotechnology, while Felt et al. (2008) found that issues such as institutional support can influence attitudes toward public participation in science and technology decisions. This paper is less focused on these more aggregate-level factors and instead focuses on individual-level influences on attitudes toward nanotechnology.

5 The mean age of respondents in our sample is somewhat higher than the national average. John Brehm (1993) has described the potential impacts that disproportional self-selection into survey samples can have on overall estimates and also on the strength of relationships. Given the nature of the relationships in our study, we do not anticipate an impact from the slightly higher mean of the age distribution in our sample.

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