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Validation and Exploration of Instruments for Assessing Public Knowledge of and Attitudes toward Nanotechnology

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Abstract The purposes of this study were to develop instruments that assess public knowledge of nanotechnology (PKNT), public attitudes toward nanotechnology (PANT) and conduct a pilot study for exploring the relationship between PKNT and PANT. The PKNT test was composed of six scales involving major nanotechnology concepts, including size and scale, structure of matter, size-dependent properties, forces and interactions, tools and instrumentation, as well as science, technology, and society. After item analysis, 26 multiple-choice questions were selected for the PKNT test with a KR-20 reliability of 0.91. Twenty items were developed in the PANT questionnaire which can be classified as scales of trust in government and industry, trust in scientists, and perception of benefit and risk. Cronbach alpha for the PANT questionnaire was 0.70. In a pilot study, 209 citizens, varying in age, were selected to respond to the instruments. Results indicated that about 70 % of respondents did not understand most of the six major concepts involving nanotechnology. The public tended to distrust government and industry and their levels of trust showed no relationship to their levels of knowledge about nanotechnology. However, people perceived that nanotechnology provided high benefits and high risks. Their perceptions of the benefits and risks were positively related with their knowledge level of nanotechnology. People's trust showed a negative relationship to their risk perception. Implications for using these instruments in research are discussed in this paper.

Keywords Attitudes toward nanotechnology · Instrument · Knowledge of nanotechnology

Abbreviations
PKNT Public knowledge of nanotechnology
PANT Public attitudes toward nanotechnology

Introduction

The Advancement of Nanotechnology

Nanotechnology has been one of the most significant scientific developments in decades. The main reason for its development is to advance broad societal goals such as improved comprehension of nature, increased productivity, better health care and an extension of the limits of sustainable development and human potential (Roco 2003). Scientists are devoted to developing nano-applications that are radically transforming a host of products to benefit human life, including battery-storage capacity (e.g. hydrogen-storage systems based on carbon nanotubes) (Scheufele and Lewenstein 2005), construction (e.g. self-cleaning windows, toilets and paints) (Parkin and Palgrave 2005), air remediation (e.g. photocatalysts) (Pacheco-Torgal and Jalali 2011), as well as disease diagnosis and medical cures (Shi et al. 2010). With this development, human exposure to nano-particles is inevitable as they

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become more widely used, especially for medical purposes, where they are utilized to detect and treat human diseases. Research has shown nano-particles' toxicity to living cells and emphasizes the importance of understanding their properties and effects (Lewinski et al. 2008). That is, on the negative side, nanotechnology may induce a variety of environmental and human health hazards. When people do not understand the basic principles and possible risks of nanotechnology, the misuse of nanotech products will decrease the efficiency of these products and possibly result in detrimental effects on human health or the environment.

Public Engagement of Emerging Technologies

Currently, communication of and public engagement in science are issues of concern in several developed nations. The idea of advocating more upstream public engagement (i.e., empowering and motivating citizens to participate at the beginning of the policy-making process) at earlier stages in science and technology development can be seen in the Royal Society and Royal Academy of Engineering (RS and RAE) report on nanoscale science and technology (RS and RAE 2004) and in the editorial of the science magazine *Nature* (Nature 2004). The literature has also indicated that a better-informed public can make more rational decisions concerning public safety issues and research funding (Sturgis et al. 2005). Therefore, nations developing nanotechnology should support public nanotechnology education and related projects for promoting upstream public engagement. Moreover, science educators should provide the public with essential knowledge of nanotechnology as a basis for social communication. Before providing nanotechnology education or inviting the democratic involvement of citizens, it is critical to investigate what the public knows about nanotechnology and how they perceive its safety, risks, and benefits.

Although considerable research has been devoted to investigating public knowledge of and attitudes toward nanotechnology (Castellini et al. 2007; Cobb and Macoubrie 2004; Kahan et al. 2007; Macoubrie 2005; Waldron et al. 2006), rather less attention has been paid to integrating existing instruments for the purpose of thoroughly covering the potential construct dimensions of the above-mentioned assessments. As nanotechnology has rapidly developed over the past decade, many new nanoproducts have appeared on the market. There is thus a need to develop instruments to better examine public understanding and perceptions of this particular field. Recently, Stevens et al. (2009) proposed nine major concepts in nanoscale science and engineering for nanotechnology education, including size and scale, structure of matter, size-dependent properties, quantum effects, forces and interactions, self-assembly, tools and instruments, models and simulations, and science-technology-society (STS). These concepts, which were identified by leading scientists, engineers, and science educators, have been used as the basis of our development of an instrument to assess public knowledge of nanotechnology. For the assessment of public attitudes toward this issue, we incorporated the construct dimensions of previous studies to construct an instrument covering both public trust and perceptions of the benefits and risks.

Background

Public Attitudes Toward Nanotechnology

Research has suggested that people's judgments of science and technology are mostly based on their feelings rather than on analytical judgment. In other words, affective processes often precede cognitive evaluation (Loewenstein et al. 2001). Previous studies of public attitudes toward new technology (Ghosh et al. 1994; Lee et al. 2005; Rodriguez and Peterson 1999) have tended to focus on affective variables including constructs such as trust, perceptions of benefits, perceptions of risks, negative emotions and alienation. Among these foci, the alienation factor does not dominate public attitudes toward new technology (Rodriguez and Peterson 1999), while the dimension of negative emotion can be represented by perceptions of risk (Lee et al. 2005). Therefore, a review of the literature led us to focus on two dimensions of affective factors: trust and perceptions of the benefits and risks. In the following two paragraphs, we discuss each of these dimensions in turn.

Trust

Trust can influence the perceptions of the risks and benefits of new technologies, as well as their public acceptance (Macoubrie 2006; Priest et al. 2003; Rodriguez and Peterson 1999). Priest (2001) proposed that judgments of the levels of risk associated with new technologies are highly related to judgments of the trustworthiness of scientists and their employers. A number of studies exploring public attitudes toward new technology have focused on three sub-dimensions: trust in government agencies, trust in business and industry, and trust in scientists in the science community (Cobb and Macoubrie 2004; Lee et al. 2005; Rodriguez and Peterson 1999). For example, Cobb and Macoubrie (2004) indicated that individuals' lack of trust in business leaders is positively related to perceptions of the risks of nanotechnology. Lee et al. (2005) reported that individuals with a lack of trust in scientists are likely to perceive more risks than benefits. Trust is a very complex idea. People may trust those who they believe have similar values or special professional knowledge. It is believed that trust is hard to gain and easy to lose and very difficult to regain or repair (Priest 2008). Science communicators are reminded to understand the dynamics of trust and to develop long-term credibility through honesty and transparency (Priest 2012). The above literature shows that public trust is an important dimension to be explored. However, research considering all of the main sub-dimensions of public trust regarding nanotechnology is still scarce.

Perceptions of Benefits and Risks

In addition to trust, previous studies exploring public attitudes toward emerging technology have assessed perceptions of technological benefits and risks (Frewer et al. 1998; Ghosh et al. 1994; Lee et al. 2005; Rodriguez and Peterson 1999). The research findings have revealed an inverse relationship between the perceived risks and benefits of the technologies studied (Frewer et al. 1998; Siegrist et al. 2000). High benefit, low risk technologies such as solar energy and informational technology tend to be more acceptable than those which are seen to be low benefit, high risk such as nuclear energy and food additives. However, a majority of American laypeople perceive nanotechnology as a high benefit, high risk technology (Cobb and Macoubrie 2004; Siegrist et al. 2007). In addition, Currall et al. (2006) found that people who believe nanotechnology to be beneficial also tend to believe that it is risky. This finding is inconsistent with public perceptions of other emerging technologies (e.g., solar energy and informational technology). As nanotechnology is expected to have great potential in creating jobs and fostering economic development (Roco 2003), further education of its potential benefits and risks in terms of the environment and individual health is needed.

Public Knowledge of Nanotechnology

The National Nanotechnology Initiative (NNI) provides a definition of nanotechnology:

> Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. A nanometer is one-billionth of a meter. A sheet of paper is about 100,000 nm thick; a single gold atom is about a third of a nanometer in diameter. Dimensions between approximately 1 and 100 nm are known as the nanoscale. Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules (NNI 2010).

The above definition refers to unique phenomena, properties, and functions at the nanoscale and also to the novel applications and abilities to measure, control, and manipulate matter at the nanoscale. It also addresses the size of one nanometer and the difference in the material properties at the nanoscale and microscale. These key concepts in the definition should be the basic knowledge of nanotechnology literacy. Some researchers have suggested that people should have a basic understanding of nanotechnology before attending any nanotechnology conferences or forums (Pecora et al. 2003). Unfortunately, a growing body of evidence has demonstrated that most people are ill-informed with regard to nanotechnology. For example, more than sixty percent of the general population in the United States do not know what nanotechnology is (Cobb and Macoubrie 2004; Kahan et al. 2007; Macoubrie 2005). Only twenty percent of the general population in England and Japan can give a simple definition of nanotechnology, and there are often mistakes in their definitions (Dowling et al. 2004; Fujita et al. 2006). In Taiwan, more than sixty percent of the public do not demonstrate a basic understanding of nanotechnology (Cheng et al. 2009).

With respect to the format of assessment items, Laugksch (2000) noted that approaches have varied among sociologists of science, social scientists, and science educators. Some researchers have used a small number of open-ended questions (Cobb and Macoubrie 2004; Macoubrie 2005; Waldron et al. 2006) or true–false items (Scheufele and Lewenstein 2005), while others have used multiple-choice items (Castellini et al. 2007; Dyehouse et al. 2008) to assess public knowledge of nanotechnology. The advantages and disadvantages of open-ended and close-ended items for the measurement of the public knowledge of science have been discussed by Miller (1998). The main criticism of close-ended items is that respondents might guess on true–false or multiple-choice questions. In contrast, open-ended formats have the potential to provide a better measurement of understanding than close-ended formats (Miller 1998). Nevertheless, previous studies have shown that most people do not have a basic understanding of nanotechnology, and thus, it would be too demanding for laypeople to use unfamiliar and newly developed scientific terminologies to explain their understanding in open-ended questionnaires (Brossard and Shanahan 2006). On the other hand, multiple-choice items provide more information about nanotechnology. Respondents can depend on their scientific literacy and awareness of nanotechnology to show their understanding without having to explain it in an open-ended fashion. Therefore, we selected the multiple-choice format to develop an instrument for the assessment of public nanotechnology literacy.

Relationship Between Public Knowledge of and Attitudes toward Nanotechnology

In general, a rational approach and a value approach are used by social researchers to explain individuals' decisions of acceptance or rejection of technology (Douglas and Wildavsky 1983; Krimsky and Plough 1988). Individuals using a rational approach make risk decisions on the basis of a personal cost-benefit analysis. From the rational perspective, the major reasons for people rejecting a technology which experts assure us is safe are mostly poor understanding or not knowing the actual objective of cost-benefit analysis (Rodriguez and Peterson 1999). In brief, if the rational perspective dominates public reactions, understanding the technology or level of education are the main factors that explain individuals' decisions of acceptance or rejection. In contrast, researchers who use a value approach argue that people use a number of qualitative dimensions in their decision-making, such as catastrophic potential, scientific uncertainty, controllability, equity, and the risk the technology poses to future generations (Slovic et al. 1979). If the value perspective dominates public reactions, affective factors become the main factors in individuals' decision-making.

Some researchers have proposed that individuals' risk perceptions are affected by pre-existing knowledge about the emerging technology (Ghosh et al. 1994; Wildavsky and Dake 1990). Along similar lines, Cobb and Macoubrie (2004) found that people with high knowledge predict greater benefits than those with low knowledge. The level of benefit perception is related to whether the benefit can be enjoyed by the majority of the population. If the risks and benefits resulting from the technology do not accrue equally across different groups within the population, emerging technologies may result in public resistance (Foreman 1990). After analyzing the relationship between risk attitude and adoption of new technologies, Ghosh et al. proposed that the reduction of risk will increase the adoption of new technology. Moreover, when a government is equally concerned about risk-reduction policies and benefit-promotion policies, people are more likely to adopt a new technology. Therefore, regular monitoring of public perceptions of nanotechnology would enable nanoscientists and policy makers to better understand or predict social acceptance of the technology.

Rodriguez and Peterson (1999) pointed out that trust in government regulatory agencies, in industry and in scientists or science itself figure prominently in the decision to accept or reject new technologies. Affective factors (e.g., trust) tend to have a stronger effect on laypeople's decision-making about their acceptance of emerging technologies than do cognitive factors (e.g., knowledge) (Lee et al. 2005; Macoubrie 2006; Rodriguez and Peterson 1999; Siegrist et al. 2007). The influence of new information on attitudes may be minimal if people rely on strong emotional heuristics to process this information. When public opinion has not yet crystallized and knowledge is low, effective public communication through moderated consensus conferences or public technology forums is important for presenting different viewpoints, for increasing public trust in the government and scientists, for reducing unnecessary exaggeration of risk perceptions, and for controlling emotional involvement (Lee et al. 2005).

Despite a range of previous studies investigating nanotechnology literacy, little attention has been paid to developing instruments which thoroughly cover the cognitive domain of nanotechnology knowledge and the affective domain of attitudes toward nanotechnology, including perceptions of benefits, risks, and trust. The primary objective of this study is therefore to develop an instrument to assess public knowledge of nanotechnology and design a questionnaire to assess public attitudes toward nanotechnology. The secondary objective of this study is to conduct a pilot study to explore the relationship between public attitudes toward and public knowledge of nanotechnology.

Methodology

Instrument Development

Two instruments were used in this study: the public knowledge of nanotechnology (PKNT) test and the public attitudes toward nanotechnology (PANT) questionnaire. For the purpose of validating the two instruments, a group of 329 university students were asked to answer the test items of PKNT and respond to the questions of PANT. One nanotechnology researcher, who had majored in thin film materials and electron microscopy, and two science educators, verified the content validity of these instruments. The experts' suggestions to modify scientific terms and add items to measure nanoscale particles with an atomic force microscope, an instrument that creates images by scanning the sample surface, were taken into consideration in revising the instruments. A 32-item multiple-choice draft of the PKNT test was used to assess public knowledge of six major concepts in nanotechnology which have been identified as necessary knowledge for scientific citizenship (Stevens et al. 2009), including size and scale, structure of matter, size-dependent properties, forces and interactions, tools and instrumentation, and science-technology-society (STS). In addition to the 32 items, six more items were used as a self-report for participants to respond about their experience of using nanotechnology products and to estimate their knowledge level of nanotechnology.

Meanwhile, three university students, two science majors and one non-science major, were individually interviewed using the PKNT test items. Each was asked to explain the meanings of the individual items, and those for which they gave ambiguous explanations were adjusted accordingly. The following item exemplifies the PKNT test (the correct answer is marked *).

Forces and Interactions Item

Which one of the following statements regarding the 'lotus effect' is *NOT* true?

a. The surface of a taro leaf possesses nano-structured materials
b. Nano-structures can enhance the hydrophobicity of a surface
c. Nano-structures can enhance the adhesion force between a surface and a droplet*
d. Water droplets are able to pick up dirt particles on a taro leaf and result in a self-cleaning process
e. I don't know

The PANT questionnaire (as shown in "Appendix"), a 20-item Likert-type instrument comprising two subscales, was used to assess public attitudes toward nanotechnology. The first subscale consisted of 10 items measuring three constructs, including trust in government agencies, trust in business and industry, and trust in scientists (e.g., When the government develops nanotechnology, do you trust that it will protect public benefits and health?). Each item was constituted using a four-point Likert-type scale (4: highly trust, 3: trust, 2: distrust, 1: highly distrust). The second subscale consisted of 10 items to measure two constructs, including perceptions of the benefits and perceptions of the risks of nanotechnology (e.g., Nanotechnology provides people with newer and better ways to cure or examine their diseases.). Each item allowed responses on a four-point scale (4: strongly agree, 3: agree, 2: disagree, 1: strongly disagree). The construct validity of the PANT questionnaire was verified by the results of the factor analysis which are presented in the results section.

Data Collection and Analysis for the Pilot Study

With the use of the convenience sampling strategy, three elementary schools located in a suburban area of southern Taiwan were selected for the pilot study. In each school, we invited one teacher to distribute the instruments, including PKNT and PANT, by randomly selecting four classes of students. These students were told the required criteria of participants and helped us invite their parents or relatives to participate in the study. In total, 330 adults with an educational background above junior high school and whose ages ranged from 18 to 65 accepted our invitation. Among 209 usable responses (63.6 % return rate), 24 % of the sample was aged 18–29; 21 % was aged 30–39; 36 % was aged 40–49; and 19 % was aged 50–65. Excel 2007 and the Statistical Package for Social Science (SPSS 12.0) were used to establish descriptive statistics for the responses to the instrument. The means and standard deviations of the PANT subscale scores for adults with different knowledge levels of nanotechnology were analyzed and compared through the statistical method of analysis of variance (ANOVA). The post hoc comparisons of Scheffe's method (Agresti and Finlay 1997) were used to check between-group differences. In addition, Pearson correlation analysis was used to examine the relationships among PKNT scores and each subscale of the PANT questionnaire.

Results

Validation and Item Analysis of the PKNT Test

Before the pilot test of the PKNT and PANT to the public adults, the drafts of the two instruments were administered to a group of university students for the purpose of validation. The first version of the PKNT test consisted of 32 multiple-choice items. After adjusting inappropriate wording, the revised version was sent to 329 university students including non-science majors and science majors, half of whom had enrolled in an introduction to nanotechnology course. Two hundred nineteen responses were received (66.5 % return rate). An itemized analysis of the PKNT test was conducted based on 218 usable responses ($n = 69$, science majors who had taken an introduction to nanotechnology course; $n = 78$, science majors who had not taken any courses about nanotechnology; $n = 71$, non-science majors). Students with science majors had significantly higher scores than non-science majors ($F = 36.42$, $p < 0.001$). This result is in accordance with Gronlund's (1985) recommendation which states that "comparing the scores of known groups" (p 75) provides construct validity if the instrument effectively discriminates between those who are science majors and those who are not. The criteria for best items were difficulty values (i.e., the index indicating the proportion of participants who answered an item correctly) ranging from 0.4 to 0.8 (Chase 1978) and discrimination values (i.e., the extent to which a test item discriminates between students who do well on the overall test and those who do not) above 0.25 (Noll et al. 1979). Because the average education background for university students is higher than that for the public, the scores of university students in the PKNT test would most likely be higher. Thus, the range of difficulty values and discrimination values should be adjusted accordingly. Items were valued by the appropriate Kuder-Richardson Formula 20 (KR-20) coefficient. When the KR-20 coefficient of the subscale became significantly higher after deletion of one item, that item was deleted.

After the item deletion procedure, the final PKNT test version consisted of 26 items. The analysis of the university students' responses demonstrated difficulty values ranging from 0.16 to 0.92, discrimination values ranging from 0.14 to 0.72, and the reliability of the PKNT was 0.78. When the PKNT was administered to a group of 209 adults, the difficulty values ranged from 0.16 to 0.89, while the discrimination values ranged from 0.14 to 0.72. The overall KR-20 reliability of PKNT is 0.91, and the reliabilities of each major concept are listed in Table 1.

Factor Analysis for the Validation of the PANT Questionnaire

A principal component analysis with varimax rotation was applied to the data collected from the 209-adult responses to the PANT questionnaire. Since all of the factor loadings of the original 20 items in the PANT questionnaire were above 0.40 and were well matched with the designated four sub-scales, all items remained in the questionnaire in accordance with the suggestions of Reise et al. (2000). The scree plot enabled us to eliminate those eigenvalues starting to form a descending linear trend. Consequently, five factors with eigenvalues above 1.0 were extracted (Reise et al. 2000). A total of 57.1 % variance was explained by these five factors. The five factors and the factor loadings for each item are shown in Table 2. The first factor consists of five items relating to trust in scientists, while the second factor consists of five more items about trust in government and industry. Altogether, the 10 items are used to assess public trust in government, industry, and scientists in managing the potential risks of nanotechnology. The third factor consists of five items to measure public awareness of potential benefits of nanotechnology. Two items of the fourth factor and three items of the fifth factor are all related to perceptions of the potential risks of nanotechnology.

Table 1 KR-20 reliability of each big idea for the PKNT test ($n = 209$)

Big idea	Item number	KR-20
PKNT	26	0.91
Size and scale	4	0.75
Structure of matter	5	0.53
Forces and interactions	6	0.81
Size-dependent properties	4	0.74
Tools and instrumentation	3	0.80
STS	4	0.50

Table 3 reveals that the Cronbach's alpha coefficient for the PANT questionnaire was 0.70 and for each scale ranged between 0.77 and 0.60. In the PANT questionnaire, the discriminate validities (i.e., mean correlations with other scales) ranged from −0.23 to 0.38. All of these values are less than 0.85, which reveals the independence of each scale and little overlap with other scales (John and Benot-Martinez 2000).

Public Knowledge of Nanotechnology

Table 4 indicates that more than 60 % of the 209 participants are not equipped with scientific understanding in five of the six major concepts that have been identified as recommended knowledge in order to function well as scientific citizens (Stevens et al. 2009). Two of the best understood ideas were 'structure of matter' and 'size-dependent properties' with PP values (i.e., the proportion of respondents who answered the items of that big idea correctly) of 38.6 and 37.4 %, respectively, while two of the least understood ideas were 'tools and instrumentation' and 'forces and interactions', with PP values of 25.2 and 25.5 %, respectively. These results are not surprising, because the idea of 'tools and instrumentation' has rarely been introduced in science textbooks, and the idea of 'forces and interactions' is one of the most abstract ideas of nanotechnology.

In addition, we found that the assessment results of people's understanding of nanotechnology were similar to their self-evaluation of their understanding of nanotechnology. In total, 72.7 percent of participants self-evaluated themselves by selecting the options 'don't understand' (62.7 %) or 'rarely understand' (10.0 %) nanotechnology. This consistency seems to support that the PKNT has successfully assessed the participants' understanding of nanotechnology.

Public Attitudes Toward Nanotechnology

In the PANT questionnaire, the scales of 'trust in government and industry' and 'trust in scientists' were used to assess public trust in government agencies, the industrial sector, and scientists in managing the development of nanotechnology. Table 5 indicates that the percentage of respondents' distrust in government and industry (59.0 %)

Table 2 Rotated factor loadings for items in the PANT (ordered by loading, $n = 209$)

	Item	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Trust in scientists	3	0.74				
	4	0.69				
	1	0.66				
	2	0.65				
	5	0.64				
Trust in government and industry	2		0.80			
	1		0.78			
	3		0.68			
	4		0.58			
	5		0.46			
Benefits	5			0.82		
	4			0.77		
	2			0.52		
	1			0.48		
	3			0.44		
Risks	3				0.79	
	1				0.78	
	5					0.76
	4					0.68
	2					0.54

All loadings smaller than 0.4 have been omitted

Table 3 Internal consistency (Cronbach alpha coefficient) and discriminate validity (mean correlation with other scales) for the PANT ($n = 209$)

Scale	Item number	Mean	SD	Cronbach alpha	Mean correlations with other scales
Trust in scientists	5	12.37	2.17	0.76	0.38***
Trust in government and industry	5	11.80	2.13	0.77	0.23***
Benefits	5	14.79	1.41	0.61	0.37***
Risks	5	14.67	1.71	0.60	−0.23***

*** $p < 0.001$

Table 4 Descriptive statistics for the PKNT ($n = 209$)

Major concept	Correct (%)	Wrong (%)	Don't know (%)
Size and scale	31.1	24.6	44.3
Structure of matter[a]	38.6	51.8	9.7
Forces and interactions	25.5	31.4	43.2
Size-dependent properties	37.4	14.2	48.3
Tools and instrumentation	25.2	21.1	53.7
STS	54.4	21.4	24.2

[a] Most of the items in the subscale of 'structure of matter' do not provide the choice of 'don't know'

Table 5 Public perceptions of trust, benefits, and risks of nanotechnology ($n = 209$)

Trust	Trust (%)	Distrust (%)
Trust in government and industry	41.0	59.0
Trust in scientists	50.4	49.6
Benefits and risks	**Agree (%)**	**Disagree (%)**
Benefits	87.8	12.2
Risks	82.6	17.4

is higher than their trust in these two groups (41.0 %). Moreover, half of the respondents (49.6 %) did not trust scientists. The other evidence indicated that respondents' distrust is consistent with their commercial decision-making behavior. When respondents were asked 'Do you prefer to buy nano-products recommended by experts?' in the self-report about nanotechnology, a majority were 'not sure' (60.8 %), and only a few respondents preferred experts' recommendations (22.5 %). These results indicate that the respondents do not trust scientists to guide their purchasing behavior.

Table 6 One-way ANOVA of responses with different knowledge of nanotechnology on the PANT ($n = 209$)

	High knowledge ($n = 39$)		Moderate knowledge ($n = 133$)		Low knowledge ($n = 37$)		ANOVA results	
	Mean	SD	Mean	SD	Mean	SD	*F*	Post hoc
Trust (S)[a]	12.33	1.74	12.36	2.20	12.43	2.49	0.02	
Trust (G + I)[a]	11.31	1.59	11.92	2.20	11.92	2.34	1.30	
Benefits	15.49	1.28	14.81	1.39	13.97	1.24	12.14***	High > moderate Moderate > low High > low
Risks	15.51	1.52	14.68	1.71	13.73	1.43	11.35***	High > moderate Moderate > low High > low

[a] Trust (S) means trust in scientists, and trust (G + I) means trust in government and industry

*** $p < 0.001$

The scales of 'benefit' and 'risk' were used to measure public perceptions of potential benefits and risks of nanotechnology. Table 5 indicates that most people agreed that nanotechnology brings not only benefits (87.8 %) but also risks (82.6 %). In brief, most of the respondents distrusted government and industry, and they did not have much trust in scientists or scientific experts, either. The respondents perceived that nanotechnology was an emerging technology with both high benefits and high risks.

Relationship Between Public Knowledge of and Attitudes Toward Nanotechnology

One-way ANOVA was conducted to examine whether respondents with different knowledge levels of nanotechnology showed significant differences on each subscale of the PANT scores. The adults were divided into three groups—high, medium, and low knowledge of nanotechnology (e.g., high knowledge level means that the respondent's knowledge of nanotechnology is one standard deviation above the mean of all adults, while low knowledge level indicates one standard deviation lower than the mean). Table 6 indicates that respondents with different knowledge levels showed no significant difference in trust in scientists ($F = 0.02$, $p = 0.978$) or in trust in government and industry ($F = 1.30$, $p = 0.274$). Moreover, the means of 'trust in scientists' and 'trust in government and industry' were near the neutral score (mean = 12.5). In general, respondents have a slightly greater distrust in government and industry than in scientists.

However, there was significant difference on subscales of benefit and risk perceptions among different knowledge level groups ($F_{benefits} = 12.14$, $p < 0.001$; $F_{risks} = 11.35$, $p < 0.001$). The post hoc comparison indicated that respondents with higher knowledge perceived that nanotechnology had more benefits and risks than those with lower knowledge of nanotechnology. These results indicate that the respondents' knowledge of nanotechnology was not related to their amount of trust, but was strongly associated with their perceptions of the potential benefits and risks of nanotechnology.

In order to further examine the relationship between public knowledge of nanotechnology and their respective attitudes, correlation analysis was conducted. The correlation results between each subscale in the PANT questionnaire with the knowledge scores in the PKNT are presented in Table 7. The PKNT had significant correlation with the subscales of benefits and risks, while there was no significant correlation with the two subscales of trust. These results suggest again that respondents' trust in government, industry, and scientists is not related to their knowledge of nanotechnology, but that their perceptions of the benefits and risks are significantly related to their knowledge of nanotechnology. It is notable that two subscales of trust are negatively correlated with the subscale of risk ($r_{trust(G+I)\_risks} = -0.343$, $p < 0.001$; $r_{trust(S)\_risks} = -0.214$, $p = 0.002$). The results indicate that respondents' perceptions of nanotechnology risks are associated with their amount of distrust. It is understandable that people would perceive emerging technologies as having more risks when they had less trust in government, industry, and scientists.

Table 7 Pearson correlation analysis of the PANT with the PKNT ($n = 209$)

	PKNT	Trust (S)[a]	Trust (G + I)[a]	Benefits
Trust (S)[a]	0.006			
Trust (G + I)[a]	−0.091	0.495***		
Benefits	0.383***	0.311***	0.179**	
Risks	0.313***	−0.214***	−0.343***	0.152*

[a] Trust (S) means trust in scientists, and trust (G + I) means trust in government and industry

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.005$

Discussion and Implications

Stevens et al.'s (2009) identification of major concepts in nanoscience and nanotechnology education has allowed us to further develop an instrument consisting of most of the major concepts rather than focusing on certain concepts only. Although we can never really assess what participants' actual understanding of nanotechnology is, the results measured by an instrument covering major concepts, combined with the information of self-reports, provide a clearer picture and give us greater confidence in our inference of their understanding.

Compared with the abstract (e.g., forces and interactions) and unfamiliar concepts (e.g., tools and instrumentation), more respondents could provide correct responses about the concepts of 'structure of matter', 'size-dependent properties', and 'STS' due to the basic concepts learned in school science. The lack of public understanding of abstract concepts or microscopic representations in science is consistent with the findings of previous studies for the assessment of high school or university students' understanding of abstract or difficult learning topics such as gas laws (Lin et al. 2000), or forces and motion (Oliva 2003). Effective teaching strategies such as analogies (Harrison and Treagust 2000), modeling and visualization (Gilbert 1993), or multiple representation and animation (Frailich et al. 2009) have been used successfully in promoting student understanding. With an attempt at promoting student understanding of invisible and abstract science concepts (such as viruses and the nanoscale), Jones et al. (2003, 2006) found that the addition of haptic feedback from a haptic-gaming joystick not only made the instruction more engaging, but also improved student understanding of abstract science concepts. Similar to the use of analogies, models, and animation in the above literature, the addition of touch to software applications has also made it possible to extend students' interactions with computer visualizations, rather than simply examining a virtual object visually. It can be seen that most of the instructional studies focus on school age students' learning, while little attention has been paid to the promotion of public citizens' knowledge of abstract concepts or microscopic representations. Insights gained from previous studies of secondary and university students can be used to direct future studies in promoting adult understanding of abstract concepts in science.

The results of this study are similar to those of previous studies about public perceptions of nanotechnology as a high benefit and high risk technology (Cobb and Macoubrie 2004; Siegrist et al. 2007), as well as the positive correlation between public perceptions of the risks and benefits of nanotechnology (Lee et al. 2005). These results also reveal that most of the people in this study do not trust the government or industry, which is consistent with the findings of studies in the United States (Cobb and Macoubrie 2004; Macoubrie 2006). As Priest (2012) indicated, trust is easy to lose and then very difficult to regain. The alarming signal of laypeople's low trust in government agencies, the industrial sector, and scientists should remind stakeholders in science communication to pay more attention to source credibility and trust as central issues.

The above results provide some implications for policymakers and science educators who are responsible for developing nanotechnology. First, the government should concern itself with the public's trust in government and diminish the perception of unrealistic risks. For example, the government should initiate laws and set up agencies to identify standards or requirements of nano-products for the protection of consumers, propose laws and procedures to manage the potential risks, and provide industry norms to protect the environment and human health. Second, industry should provide not only the benefits of nano-products, but also the assurance of certified nano-products. Moreover, they can propose strategies for environmental protection and risk management. Finally, scientists and science educators should provide scientific information (especially those abstract concepts such as in the subscales of "forces and interactions" and "tools and instrumentations") about nanotechnology for the public using mass media to promote people's understanding of nanotechnology. In brief, a nation developing nanotechnology should not only address research and the applications of nanotechnology, but should also work to increase people's trust and reduce unnecessary exaggeration of risk perceptions.

Our results reveal that citizens with a better knowledge of nanotechnology have more positive attitudes than those with a moderate or low knowledge. These findings are similar to those of a previous study (Cobb and Macoubrie 2004). Thus, promoting public knowledge of nanotechnology is likely to enhance public perceptions of benefits and decrease their perceptions of unrealistic risks. The importance of risk education has also been emphasized by researchers who indicated that risks of science and technology play a significant role in public discussion of emergent technology (Gardner et al. 2010). More importantly, affective factors tend to have strong effect on laypeople's decision-making about their acceptance of emergent technologies (Lee et al. 2005; Siegrist et al. 2007). Therefore, the government should provide the public with opportunities to learn about major concepts of nanotechnology and its potential risks as a basis for public engagement.

This article adds to the current literature because it provides documented constructs and validated instruments which integrate the knowledge of the current literature and the constructs used in previous studies to gain insights into both public knowledge of and attitudes toward nanotechnology. As science communication has made a considerable shift away from simply informing the public and measuring its scientific literacy (i.e., a sender–receiver communication style) to more democratic public engagement at earlier stages in science and technology development (Kurath and Gisler 2009), the instruments validated in this study can serve as tools to gain better insights into public knowledge of and concerns about nanotechnology. More importantly, the information gained from the instruments will enable policymakers and science educators to make necessary decisions or to plan science communication programs matching the needs of public citizens.

Despite the fact that the items of PKNT have been carefully developed, reviewed by experts, pilot tested, and revised accordingly, even these items have equipped with reasonable difficulty values and appropriate discrimination values, readers are reminded that the expert group is small. Therefore, further revisions might be needed.

Compared to educational programs for school children, there is scant empirical analysis of programs designed for adult science learners (Bell et al. 2009). As nano-products become more widely used, public educational programs intended to develop laypeople's knowledge of nanotechnology and to foster dialog and partnership among governments, industry, scientists, and citizens are worthy of empirical scrutiny. In this study, we have developed instruments to assess public knowledge of and attitudes toward nanotechnology and have found significant relationships among knowledge level and attitudinal variables. Further research studies of using these instruments to investigate the impact of nano-education programs are recommended.

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Appendix: The Questionnaire Items on the PANT

Trust in Scientists

1. Do you trust scientists' reports about the research outcomes of emerging technologies? (e.g., nanotechnology)
2. Do you trust that all emerging technologies developed by scientists are good?
3. Do you trust that scientists understand what is good for the public?
4. Emerging technologies are complicated. Do you trust that scientists would explain them clearly to improve public understanding?
5. Do you trust the new tech products recommended by experts (e.g., scientists, doctors)?

Trust in Government Agencies and Industry

1. Do you trust in government agencies' (e.g., Department of Environmental Protection, Department of Health) management/control of emerging technology products? (e.g., nanotech products)
2. When the government develops emerging technologies, do you trust that it will protect public benefits and health? (e.g., nanotechnology)
3. Do you trust in the security guarantees for emerging technology products made by the industrial sector? (e.g., nano-toilets, nano-cosmetics, nano-photo-catalysts)
4. Do you trust the advertisements of emerging technology products made by the industrial sector?
5. Do you trust that current industries would decrease the potential risks produced by the development of emerging technologies?

Perception of Benefits

1. The development of nanotech products would bring people more advantages than disadvantages.
2. Nanotechnology can provide people with newer and better ways to cure or examine their diseases.
3. Nanotechnology cannot provide people with newer and better ways to make the environment clean. (–)
4. Nanotechnology would make our lives more comfortable.
5. Nanotechnology can enhance the efficacy of high-tech products.

Perception of Risks

1. Nanotechnology would not hurt our health. (–)
2. The toxicity of nano-particles may be even higher than that of large-size particles.
3. Nanotechnology would not pollute our environment. (–)
4. Nanotechnology may lead to competition between the military forces of some countries.
5. Tiny monitors developed in nanotechnology may result in loss of privacy.

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