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Development of an Instrument to Measure Undergraduates' Nanotechnology Awareness, Exposure, Motivation, and Knowledge

Melissa A. Dyehouse · Heidi A. Diefes-Dux · Deborah E. Bennett · P. K. Imbrie

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Abstract There are many educational interventions being implemented to address workforce issues in the field of nanotechnology. However, there is no instrument to assess the impact of these interventions on student awareness of, exposure to, and motivation for nanotechnology. To address this need, the *Nanotechnology Awareness Instrument* was conceptualized. This paper is a progress report of the instrument development process. Version 1 of the instrument was administered to 335 first-year students majoring in food and agriculture fields in a pre–post fashion relative to a brief exposure to nanotechnology in the classroom. Following item analysis of Version 1 responses, a revision of the instrument was completed. Version 2 was administered to 1,426 first-year engineering students for the purpose of conducting item and factor analyses. Results indicate that the *Nanotechnology Awareness Instrument* shows potential to provide valid information about student awareness of, exposure to, and motivation for nanotechnology. The instrument is not a valid measure of nano-knowledge and this subscale was dropped from the final version of the instrument. Implications include the use of the instrument to evaluate programs, interventions, or courses that attempt to increase student awareness of nanotechnology. Further study is necessary to determine how the *Nanotechnology Awareness Instrument* functions as a pre–post measure.

M. A. Dyehouse · D. E. Bennett
101 University Street, West Lafayette, IN 47907-2098, USA

H. A. Diefes-Dux (✉) · P. K. Imbrie
School of Engineering Education, 701 W. Stadium Avenue, West Lafayette, IN 47907-2045, USA
e-mail: hdiefes@purdue.edu

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Introduction

Nanotechnology is a relatively new field, and as such is not yet widely understood by the public. Yet, the worldwide workforce that is estimated to be necessary to support the field of nanotechnology by 2015 is 2 million (Roco and Bainbridge 2001). The President's 2007 Budget provided over $1.2 billion for the National Nanotechnology Initiative (NNI 2006); this brought the total U.S. investment since 2001 to over $6.5 billion. While this field is experiencing considerable growth due to its enormous potential to affect many facets of society, the demand for nanotechnology experts may far exceed the number of students pursuing academic paths leading to careers in nanotechnology (Roco 2003). This may be due in part to a lack of awareness about nanotechnology and what academic preparation and career options exist in the field. As there is a need to develop appropriate interventions or methods to increase students' awareness, exposure, motivation, and factual knowledge, a valid instrument is needed. This paper reports on the development and refinement of an instrument to measure various constructs that were deemed important in increasing motivation to pursue further studies of nanotechnology.

Investigations into Awareness

Several surveys have shown that the majority of the public has little to no awareness or knowledge about nanotechnology (Cobb and Macoubrie 2004; Gaskell et al. 2003; Macoubrie 2005; Royal Society and Royal Academy of Engineering 2004). For example, in a 2005 study on the

American public's perceptions of nanotechnology, the majority of participants (54%) reported that they knew almost nothing about nanotechnology, while 26% said that they knew a little, and 17% said that they knew something about nanotechnology (Macoubrie 2005). There is also a lack of awareness among secondary school students; few have heard about nanotechnology (Fonash 2001). It follows that postsecondary students may share a similar lack of awareness and factual knowledge about nanotechnology.

In the university setting, several actions have been taken to promote awareness and factual knowledge among students about the uses of nanotechnology and academic and career options that exist within the field. One method is the implementation of semester long nanotechnology courses that cover nanotechnology applications in a particular field. For example, the Foundation Coalition, a National Science Foundation (NSF) funded engineering education coalition made up of eight partner campuses, integrated nanotechnology into three main undergraduate engineering courses at Texas A&M University. The first component integrates nanotechnology in two modules in the sophomore engineering course, Principals of Materials Engineering (ENGR 213). The second component integrates nanotechnology in two 1-h modules in a junior-level course, Materials and Manufacturing Selection in Design (MEEN 360). The third course is an elective available to all engineering and science students who have completed the first two courses and expands on the previous modules about nanotechnology (Froyd et al. 2004).

Additionally, the NSF has awarded several grants to fund the implementation of undergraduate courses and laboratories in nanotechnology that allow students to become acquainted with the field. The NSF's Nanotechnology Undergraduate Education program (National Science Foundation 2005) has awarded grants to several colleges and universities, for example, Michigan Technological University (National Science Foundation 2004a, b), Clarkson University (National Science Foundation 2004a, b), Oregon State University (National Science Foundation 2006), and Purdue University (Diefes-Dux et al. 2004). Also funded were six universities that form the National Center for Learning and Teaching in Nanoscale Science and Engineering, which will train educators to introduce nanoscience and engineering into high schools and undergraduate programs (Telford 2004).

Nanotechnology awareness may also be gained by hands-on laboratory learning experience. Programs that offer students nanotechnology lab experiences usually include research opportunities. One example of a laboratory research opportunity is provided by the National Nanotechnology Infrastructure Network (NNIN). This center hosts a Research Experience for Undergraduates Program each summer at 12 different sites (NNIN 2004).

It is necessary to examine whether programs like these are effective in promoting awareness and exposure to nanotechnology as well as increasing motivation to pursue nanotechnology as a field of study or career. To do this, an appropriate instrument must be created to effectively measure relevant facets of student awareness of, exposure to, and motivation for nanotechnology.

Need for an Awareness Instrument

Few instruments have been developed to measure nanotechnology awareness. The majority of these instruments deal with public awareness and factual knowledge about nanotechnology. One of the earliest of these is an Internet survey questionnaire on public attitudes about nanotechnology (Bainbridge 2002). This survey, which is part of a broader social science survey sponsored by the National Geographic Society and the NSF, includes three nanotechnology-related questions. An additional open-ended response was also administered to a fourth of the participants who took the original survey. Responses given by these participants were compiled into themes by the author, who suggested that they could be used as a model for developing an instrument on public attitudes towards nanotechnology. There were several main themes: (a) confidence that nanotechnology will benefit mankind, (b) hopefulness, but uncertainty that nanotechnology will benefit society, (c) a sense that nanotechnology will contribute to progress in science, (d) a belief that nanotechnology will benefit industry and the economy, (e) expectations that nanotechnology will contribute to the improvement or development of new materials, (f) support for the application of nanotechnology in electronics, (g) support for the application of nanotechnology in medicine, (h) doubt or ambivalence about nanotechnology, and (i) concerns about exploitation of nanotechnology or direct opposition to nanotechnology research.

Nanotechnology awareness has also been measured in a national phone survey of Americans' perceptions about nanotechnology (Cobb and Macoubrie 2004). This survey included one item designed to measure respondents' familiarity with, or exposure to, nanotechnology. In addition, respondents' factual knowledge about nanotechnology was measured by three true/false items. Also measured were respondent perceptions of nanotechnology risks and benefits, emotional reactions to nanotechnology, levels of trust in technology business leaders, and views of science in general. Again, this survey may not be specific enough to tap various facets of awareness and knowledge that might lead students to pursue an academic or career path in nanotechnology.

One nanotechnology survey, which took place in the United Kingdom, was administered to a representative sample of the general public, 1,005 participants aged 15 and above (Royal Society and Royal Academy of Engineering 2004). This brief survey contained several items that dealt with awareness of and factual knowledge about nanotechnology. One question asked participants if they had heard of nanotechnology then asked them to provide a definition of nanotechnology. The survey asked those individuals who had heard of nanotechnology about the potential effects nanotechnology would have in the future. The results of the survey showed that only three in 10 respondents claimed to have heard of nanotechnology. Awareness was higher among men, older respondents, and those of higher socio-economic standing. Knowledge about nanotechnology was low even for those who had an awareness of nanotechnology.

Another European survey that took place in 2002 included an item asking whether nanotechnology would improve our way of life in the future (Gaskell et al. 2003). This item, while an important indicator of attitude towards the field of nanotechnology, does not provide enough information about what a person thinks and knows about nanotechnology.

It is evident that an instrument is needed to measure nanotechnology awareness, exposure, and motivation of undergraduate students. This instrument should be able to capture changes over time; as such information will indicate whether a particular program or intervention is effective for increasing nanotechnology awareness and knowledge or for motivating students to pursue further studies in nanotechnology. Knowing the degree to which programs increase various facets of student awareness, knowledge, and motivation will also aid in making curricular design decisions.

Previous instruments that have focused on measuring public awareness of nanotechnology are not specific enough to function as a pre and post measure of students' awareness. Public awareness surveys have measured nanotechnology awareness in a very general sense. The awareness that an undergraduate might gain through a nanotechnology educational intervention is more specific, including terminology associated with nanotechnology, applications of nanotechnology, and career options in nanotechnology.

Additionally, previous surveys have not made a distinction between the categories of awareness, exposure, or motivation. Subscales that measure each construct can provide information about which constructs are most affected by an intervention and which interventions increase all three constructs the most. It is necessary to establish awareness about nanotechnology because a student must first be aware of the field before he or she can be motivated to pursue nanotechnology as a field of study or career. Metacognition leads to meaningful learning (Baird 1986) and this knowledge may influence students to learn more about the field of nanotechnology. Metacognition can be defined as the awareness and control of one's own learning (Baird 1986). Knowing what students believe they know; that is, perceived awareness about nanotechnology is expected to improve over the course of a successful intervention.

Exposure to nanotechnology is another construct that must be assessed because the level of exposure may be examined for resulting increases in motivation or factual knowledge about nanotechnology. It follows that a subscale measuring motivation must be included to determine if the program or intervention has an effect on this construct. In addition, if the goal of a program or intervention is to increase factual knowledge about nanotechnology then a subscale measuring this can be included.

One method of increasing students' motivation to pursue nanotechnology as a field of study or career is to provide opportunities for awareness and exposure to nanotechnology. Because of the growing demand for nanotechnology experts, it is clear that many students are needed. In order to satisfy the pipeline requirements for a trained workforce, it is critical to determine if the programs or courses put in place have an effect on students' awareness, exposure, and motivation to pursue the study of nanotechnology.

The primary goal of this study was to develop and refine an instrument that reliably measures the constructs of nanotechnology awareness, exposure, motivation, and knowledge. The main research question for this study is: Is the *Nanotechnology Awareness Instrument* a valid and reliable measure for nanotechnology awareness, motivation, exposure, and knowledge? More specifically, do the subscales form separate unidimensional constructs of awareness, exposure, and motivation? Additionally, is the instrument capable of showing changes following an intervention? This paper describes the development and analysis of the *Nanotechnology Awareness Instrument*.

Method

Instrument Development

The *Nanotechnology Awareness Instrument* was developed to assess changes in student awareness of, exposure to, and motivation for nanotechnology as well as factual knowledge about nanotechnology before and after an educational intervention such as a course, learning module, or laboratory experience. Items were intentionally generated in each category and reviewed by content experts from various disciplines involved in developing nanotechnology interventions (i.e., Agronomy, Food Science, Agricultural and Biological Engineering, and Engineering Education). In essence, what it means to be aware of nanotechnology was defined through the generation of the awareness category items, which constituted self-reporting of an ability to name or describe basic things about nanotechnology, such as what it is, how it is applied, and its potential impact. The exposure and motivation items were intended to measure students' level of exposure to and motivation for learning nanotechnology by identifying activities that students could engage in to learn about nanotechnology. These category items constituted a brainstormed list of means and venues for learning about nanotechnology and intentionally ranged from passive to active engagement in learning. The factual knowledge items were intended to confirm select self-reported awareness claims. The researchers refined the wording and checked the sorting of the items into the four subscales, and the content experts provided final feedback on the items.

The instrument is divided into four different subscales, the first of which is titled Nano-Awareness. The concept of nanotechnology awareness as it is used in the name of the instrument is meant to reflect meta-cognition about nanotechnology—what students think they know about nanotechnology. The concept of exposure (Nano-Exposure) deals with activities that a student has actually completed, such as reading about nanotechnology. The concept of motivation (Nano-Motivation) is meant to capture the kinds of nano-related studies or work that a student plans to do in the future. The Nano-Knowledge subscale is comprised of questions that have a right or wrong answer about nanotechnology.

The *Nanotechnology Awareness Instrument* is divided into two parts. Part A contains Awareness, Exposure, and Motivation—associated items are self-reported in nature. The subscale Nano-Awareness has eight items that measure how aware students are of the impact and application of nanotechnology. Items are rated on a 5-point Likert scale from Strongly Disagree to Strongly Agree. The second subscale, Nano-Exposure, measures exposure and experience with nanotechnology. Respondents are asked to check any of the six statements that apply to their exposure to nanotechnology. The third subscale, Nano-Motivation, contains five statements that describe types of nano-related activities that a student might choose to pursue in the future. Students are asked to check any of the statements that apply.

Part B of the *Nanotechnology Awareness Instrument* contains two subscales that are meant to measure factual knowledge about nanotechnology—items included in this part have a correct answer. The first section, Nano-Knowledge, measures knowledge about nanotechnology facts. There are eight items, each containing several incorrect responses and one correct response. An additional item asks for opinions on how nanotechnology will affect our way of life in the future. A second section of Part B is meant to provide descriptive information about how familiar students are with nanotechnology uses and equipment. Seven items allow students to check all the choices that apply.

First Implementation

Version 1 of the instrument was administered as an online web survey to first-year Food and Agriculture students who were enrolled in AGR 101, Introduction to the School of Agriculture and Purdue University, a one-credit, letter-graded, 8-week seminar. In the second week of classes in Fall 2004, two presentations were devoted to the topic of nanotechnology. Prior to the first seminar, students were asked to complete the (pre) *Nanotechnology Awareness Instrument*.

The first seminar, entitled Nanotechnology I: Perspective on Size, was presented by professors in Agronomy, Agricultural and Biological Engineering, and Food Science. The seminar began with an analogy drawn between satellite pictures of objects on earth and images created using an atomic force microscope. The term nano was defined and examples of "small" were provided by investigating storage space on CDs and DVDs. Unique properties of small particles were also highlighted. One professor also began to talk about naturally occurring nanomaterials—clay minerals. A second professor discussed self-healing materials that mimic biological systems. The third professor discussed biological nanotechnology factories, focusing on bacteriophages and magnetotactic bacteria.

Prior to the second seminar, students were assigned to read Richard P. Feynman's classic talk on the potential of a very small world—*There's Plenty of Room at the Bottom* (Feynman 1959). Each presenter in the second seminar, entitled Nanotechnology II: Applications in Agriculture and Beyond, provided more in-depth descriptions of nanotechnology applications in bio-sensors, microscale separation devices, materials development, drug delivery systems, and energy. The seminar concluded with a listing of opportunities for first-year students to gain more exposure to nanotechnology.

Students were instructed to complete the (post) *Nanotechnology Awareness Instrument* during the eighth (last) week of the AGR 101 course. Version 1 was administered to 335 first-year food and agriculture students who were enrolled in AGR 101 in Fall 2004. A total of 484 students completed either the pre- or post-instrument; however, 114 students were eliminated from the study as they did not complete both the pre and the post instrument. In addition, 35 students were removed from the survey analyses because they responded on one of the post survey items that they had never heard of nanotechnology. It was assumed that their responses to any other items on the post survey could not be valid.

Second Implementation

Version 2 of the survey (Appendix) was administered as a web survey in the Fall of 2005 to 1,426 first-year students who were enrolled in ENGR 100, Freshman Engineering Lectures, a 16-week, one-credit, pass–fail graded seminar series. This course introduces first-year engineering students to the various engineering fields of study offered at Purdue University, enabling students to make an informed decision about which engineering field to pursue. Faculty representatives from each school within the College of Engineering make a presentation about undergraduate study in their field; nanotechnology may or may not have been discussed as part of these presentations. The instrument was administered mid-semester in this course as a means of performing item and factor analyses on this new version of the instrument.

Statistical Analysis

McNemar's test for paired data was conducted to determine if Version 1 was capable of detecting changes from pre to post administration. This test was used because the same subjects are responding to the items under two different conditions (before and after the nanotechnology intervention). Data were dichotomized to reflect agreement with an item (Agree and Strongly Agree) and neutrality or disagreement with an item (Neutral, Disagree, and Strongly Disagree). To avoid Type 1 errors, a Bonferroni correction was applied at the alpha level of 0.05 for each subscale.

Item difficulty and discrimination values were calculated for the Nano-Knowledge subscale. Difficulty values (p) are the proportion of examinees that answer an item correctly. These values may range from 0.00 to 1.00, with higher values indicating an easier item. Item discrimination indices are used to estimate the extent to which success on an item corresponds to success on the whole measure. These indices indicate the extent to which items are discriminating between students with high nanotechnology knowledge and low nanotechnology knowledge as measured by the total Nano-Knowledge score. Item discrimination was calculated for the Nano-Knowledge subscale using a point biserial correlation (ρ_{pbis}), which is a simplified computational formula for the Pearson product moment coefficient. The point biserial correlation represents the correlation between an item score and the total score with that item removed. The correlation should be positive, which indicates that the item is functioning correctly. An item with negative or zero value means that the item shows little or no discrimination.

An exploratory factor analysis (EFA) was carried out on selected subscales to determine if there was more than one latent construct being measured. An EFA was chosen because there is a weak literature base for measuring nanotechnology awareness and because the survey instrument is still under development.

The purpose of the factor analysis is for construct validation. An exploratory factor analysis is one of the processes used in instrument development to determine construct validity (Crocker and Algina 1986).

Results

First Implementation

Item Analysis

Internal consistency of the Nano-Awareness subscale was determined by calculating Cronbach's alpha. The (post) α-coefficient was high at 0.90. That is, the items in this subscale appeared to be measuring the same construct. The α-coefficient for the (post) Nano-Exposure items was nearly adequate at 0.67 and the (post) Nano-Motivation and (post) Nano-Knowledge subscales were below adequate at $\alpha = 0.46$ and $\alpha = 0.33$, respectively. The low Cronbach's alpha for these subscales could be due to the small number of items in each subscale.

Difficulty values for the Nano-Knowledge items changed according to pre- and post-survey responses. As expected, items were more difficult on the pre-survey, with p-values ranging from 0.04 to 0.60. Post-survey difficulty values ranged from 0.08 to 0.78 (Table 1).

Pre-survey discrimination values for the Nano-Knowledge items ranged from 0.04 to 0.39 while post-survey discrimination values ranged from 0.04 to 0.26. The high level of difficulty for the items may have caused the low item discrimination for both pre- and post-survey items.

Correlations between the Nano-Awareness, Exposure, and Motivation items and Nano-Knowledge items were investigated (Diefes-Dux et al. 2007). However, because of the high level of difficulty and low discrimination of constituent items, the Nano-Knowledge subscale was removed from Version 2 of the instrument.

Pre and Post Differences

It is necessary that the instrument be able to detect significant changes from pre- to post-administration. To examine this, McNemar's test for paired data was used to determine if the nanotechnology intervention resulted in any significant changes in nanotechnology awareness, exposure, and motivation. It is assumed that, if the

Table 1 Item difficulty and discrimination values for Version 1 of the instrument ($N = 335$)

Item	Difficulty		Discrimination	
	Pre	Post	Pre	Post
(1) When you hear the term nanotechnology, what length-scale "typically" comes to mind?	0.60	0.78	0.27	0.16
(2) Which of the following products contain nanoscale manufactured parts or materials?	0.34	0.63	0.11	0.11
(3) What is a "self-assembled monolayer"?	0.22	0.58	0.33	0.22
(4) If a nanometer were as big as the width of a pin head, about how long would a meter be?	0.23	0.41	0.39	0.26
(5) What is spintronics?	0.11	0.25	0.28	0.25
(6) Which instruments are "typically" used to make measurements at the nanoscale?	0.04	0.26	0.13	0.14
(7) The prefix "nano" comes from a Greek word meaning ____?	0.10	0.13	0.09	0.04
(8) How many hydrogen atoms lined up "shoulder-to-shoulder" would fit in a one nanometer space?	0.05	0.08	0.04	0.14

Table 2 McNemar statistics for Version 1 of the instrument ($N = 335$)

Subscale and items	No. (%) of agreement (Agree, Strongly Agree)		
	Pre	Post	χ^2
Nano-Awareness			
What is your awareness of nanotechnology? I can:			
(1) Name a nanoscale-sized object	74 (22.1%)	233 (69.6%)	135.19***
(2) Describe one way nanotechnology directly impacts my life	64 (19.1%)	248 (74.0%)	170.99***
(3) Name a field of study that currently conducts nanotechnology research	79 (23.6%)	249 (74.3%)	147.45***
(4) Describe one way nanotechnology may benefit society/humankind	93 (27.8%)	254 (75.8%)	140.11***
(5) Name an application of nanotechnology	63 (18.8%)	222 (66.3%)	142.83***
(6) Describe a process to manufacture objects at the nanoscale	20 (6.0%)	125 (37.3%)	95.87***
(7) Name an instrument used to make measurements at the nanoscale	33 (9.9%)	137 (40.9%)	81.94***
(8) Describe one way nanotechnology may directly impact my life in the future	79 (23.6%)	234 (69.9%)	129.86***
Nano-Exposure			
What is your exposure to nanotechnology? I have:			
(1) Heard the term nanotechnology	293 (87.5%)	335 (100%)	–
(2) Read [something] about nanotechnology	78 (23.3%)	252 (75.2%)	146.97***
(3) Watched a program about nanotechnology	27 (8.1%)	93 (27.8%)	47.35***
(4) Had one [or more] instructors/teachers talk about nanotechnology in class	53 (15.8%)	313 (93.4%)	248.53***
(5) Participated in an activity involving nanotechnology [lab, project,…]	7 (2.1%)	29 (8.7%)	15.13***
(6) Taken a class about nanotechnology	1 (0.5%)	16 (4.8%)	15.00***
Nano-Motivation			
What is your motivation/interest in nanotechnology? I plan to:			
(1) Read about nanotechnology	253 (75.5%)	167 (49.9%)	66.04***
(2) Investigate fields of study in which I can learn more about nanotechnology	49 (14.6%)	39 (11.6%)	2.00
(3) Take a class about nanotechnology	15 (4.5%)	23 (6.9%)	2.46
(4) Pursue an undergraduate research opportunity in nanotechnology	4 (1.2%)	7 (2.1%)	1.00
(5) Work in the field of nanotechnology	2 (0.6%)	4 (1.2%)	1.00

*** Significant at the 0.001 probability level

[a] χ^2 refers to McNemar's χ^2

intervention is successful, students will respond more positively to the Awareness and Exposure items on the post-survey than on the pre-survey.

Table 2 contains McNemar statistics for the three subscales. Using a Bonferroni correction to adjust for Type I error at the 0.05 alpha level, significance levels were recalculated for the Nano-Awareness subscale ($\alpha = 0.006$), Nano-Exposure subscale ($\alpha = 0.008$), and Nano-Motivation subscale ($\alpha = 0.01$). For the Nano-Awareness subscale, students exhibited significant pre- to post-survey gains on all nine items ($p < 0.001$). Similarly, for all of the Nano-Exposure items, students showed significant pre- to post-survey differences ($p < 0.001$). As expected, students responded as having significantly greater exposure to nanotechnology on all of the post-survey items than on the pre-survey items. Pre- and post-survey differences for the Nano-Motivation subscale were significant for one of the five items ($p < 0.001$). While it might be assumed that an intervention designed to impact awareness of nanotechnology will result in increases in awareness and exposure, it does not necessarily follow that increased exposure and awareness will motivate students to pursue nanotechnology in the future. These results suggest that the Nano-Awareness and the Nano-Exposure subscales are able to detect changes before and after an intervention targeted at awareness. Lack of significant pre–post differences for four of the five items on the Nano-Motivation subscale may be attributable to lack of sensitivity of the subscale in detecting change or due to the nature of the intervention itself.

Factor Analysis

A principal factors analysis with a promax rotation (power = 3) was carried out on the Nano-Awareness subscale. A principal factors analysis was chosen over a principal components analysis because it is assumed that the variables (items) do not have perfect reliability. Additionally, the main aim was to search for underlying constructs among the variables rather than to use this technique for data reduction. An oblique rotation was chosen because the factors represented by the scale are assumed to be related to each other.

To determine the number of factors to retain, the authors decided a priori to use several methods. These methods include the Kaiser criterion (K1 rule) of retaining factors with eigenvalues greater than 1, a scree test, and most importantly, the interpretability of the solution.

Analyses of both the pre and post Nano-Awareness subscale responses yielded one interpretable factor. These initial results suggest that the scale reflects a single, unitary construct (i.e., nano-awareness).

Second Implementation

The first implementation results prompted a revision of the instrument. For Version 2 of the survey, the Nano-Awareness subscale was not changed because of the high level of internal consistency of this subscale and the clear, interpretable factor structure. The Nano-Exposure and Nano-Motivation sections were changed to a Likert-type response format that would provide more precise information and allow for a factor analysis of the whole survey. Additionally, the Nano-Motivation subscale was revised to be modeled after an existing motivation scale, the Academic Intrinsic Motivation Scale (AIMS; French and Oakes 2003). The AIMS is made up of 25 items that measure various facets of first-year students' intrinsic motivation for academic work. The scale was created using four theoretically based intrinsic motivators: challenge, control, curiosity, and career outlook. Cronbach's alpha for the entire scale is $\alpha = 0.93$ (French and Oakes 2003).

Modeling the Nano-Motivation subscale after this instrument was thought to increase validity as well as provide additional indicators of student motivation. Relevant items on the AIMS were reworded to reflect nanotechnology indicators. For example, an AIMS item that stated *I enjoy learning more within my field of study* was reworded to state, *I enjoy learning more within the field of nanotechnology*.

For one of the Nano-Motivation items, *I plan to read about nanotechnology*, there were significantly fewer students who answered positively following the first implementation intervention than before. Because of this, Version 2 was revised to more specifically determine how motivation is affected regarding reading about nanotechnology. The item was broken down into three parts, which were: *I plan to read a fiction story about nanotechnology*, *I plan to read a news story or magazine article about nanotechnology*, and *I plan to read a research article about nanotechnology*.

Item Analysis

The internal consistency Cronbach's α-coefficient for the Nano-Awareness scale is 0.91. This result is similar to that obtained in the first implementation of the Nano-Awareness subscale. Cronbach's alpha for the pre Nano-Exposure subscale is 0.82 and for the pre Nano-Motivation subscale Cronbach's alpha is 0.94. These coefficients indicate a satisfactory level of internal consistency reliability.

Factor Analysis

An exploratory factor analysis for the Nano-Awareness, Nano-Motivation, and Nano-Exposure subscales was conducted to determine what underlying constructs were being measured. The large sample ($N = 1{,}426$) was expected to provide a robust analysis of the data.

A principal factors analysis with a promax rotation (power = 3) was used. Originally, five factors were retained according to the K1 rule. However, only four variables loaded onto the fifth factor. The scree plot revealed a leveling off after three factors, so a 3-factor solution was obtained. However, the 3-factor solution was not interpretable, so a 2-factor solution was interpreted. Previous research has found that the number of components retained by the K1 rule and the scree test is often an overestimate (Hubbard and Allen 1987; Zwick and Velicer 1986).

The 2-factor solution provided the simplest structure. Table 3 contains pattern coefficients, structure coefficients, and communality estimates. The structure coefficients are the correlations of the variables with the factors and should be used as the basis of interpretation of the factors (Gorsuch 1983). Examination of the structure coefficients suggests that the factor solution is ideal. That is, the structure coefficients have similar loadings on the same factors as the pattern coefficients. In addition, the structure coefficients between variables loading highly on one factor show low loadings on the other factors. This is an indication of simple structure.

Only one item did not load above 0.30 on either factor. This item is *I have taken a class about nanotechnology*. All of the Nano-Motivation items loaded on factor 1, with pattern coefficients ranging from 0.43 to 0.84. The remaining items, which were made up of the Nano-Awareness and Nano-Exposure items, loaded onto factor 2. Pattern coefficients for the second factor ranged from 0.26 to 0.85. Loadings of 0.71 or above are considered excellent, 0.63–0.70 are considered very good, 0.55–0.62 are considered good, 0.45–0.54 are considered fair, 0.32–0.44

Table 3 Pattern coefficients, structure coefficients, and communality estimates for Version 2 of the instrument ($N = 1{,}426$)

Item	Pattern and structure coefficients[a]		Communalities
	Factor 1	Factor 2	
Investigate fields of study in which I can learn more about nanotechnology	0.84 (0.83)	−0.02 (0.42)	0.69
Enroll in a course about nanotechnology	0.82 (0.78)	−0.07 (0.36)	0.62
Obtain a work experience or undergraduate research opportunity related to nanotechnology	0.81 (0.81)	−0.01 (0.42)	0.66
Apply or interview for a nanotechnology related work or research experience	0.81 (0.80)	−0.01 (0.41)	0.64
Attend a non-course related seminar about nanotechnology	0.79 (0.76)	−0.06 (0.35)	0.57
Visit an industry or business that specializes in nanotechnology	0.78 (0.75)	−0.07 (0.34)	0.56
Seek information about internships or co-op experiences with companies engaged in nanotechnology	0.76 (0.77)	0.00 (0.40)	0.59
Investigate the implications of nanotechnology	0.73 (0.75)	0.05 (0.42)	0.57
Read a research journal article about nanotechnology	0.67 (0.68)	0.03 (0.37)	0.47
Give a presentation related to nanotechnology to an audience I perceive as having less experience with nanotechnology than I	0.66 (0.69)	0.04 (0.39)	0.47
Informally/casually teach someone something about nanotechnology	0.65 (0.71)	0.11 (0.44)	0.51
Watch a program about nanotechnology	0.61 (0.64)	0.06 (0.38)	0.41
Formally teach nanotechnology concepts (e.g., as a teaching assistant)	0.60 (0.59)	−0.02 (0.29)	0.34
Read a news story or popular magazine article about nanotechnology	0.57 (0.62)	0.11 (0.40)	0.40
Give a presentation related to nanotechnology to an audience I perceive as having more experience with nanotechnology than I	0.56 (0.60)	0.07 (0.36)	0.36
Read a fiction story about nanotechnology	0.43 (0.49)	0.11 (0.33)	0.24
Name an application of nanotechnology	−0.07 (0.37)	0.85 (0.82)	0.67
Describe one way nanotechnology may benefit society/humankind	−0.02 (0.41)	0.82 (0.82)	0.66
Describe one way nanotechnology directly impacts my life	−0.04 (0.37)	0.80 (0.78)	0.60
Describe one way nanotechnology may directly impact my life in the future	0.01 (0.42)	0.79 (0.79)	0.63
Name a field of study that currently conducts nanotechnology research	−0.05 (0.35)	0.78 (0.76)	0.57
Name a nanoscale-sized object	−0.04 (0.34)	0.74 (0.72)	0.52
Read [something] about nanotechnology	0.12 (0.47)	0.68 (0.74)	0.56
Watched a program about nanotechnology	0.06 (0.39)	0.63 (0.66)	0.44
Heard the term nanotechnology	0.06 (0.38)	0.62 (0.65)	0.42
Describe a process to manufacture objects at the nanoscale	0.03 (0.34)	0.59 (0.60)	0.37
Had one [or more] instructors/teaches talk about nanotechnology in class	0.03 (0.31)	0.54 (0.56)	0.31
Name an instrument used to make measurements at the nanoscale	0.08 (0.34)	0.50 (0.54)	0.29
Participated in an activity involving nanotechnology [lab, project,…]	0.06 (0.25)	0.38 (0.41)	0.17
Taken a class about nanotechnology	0.05 (0.18)	0.26 (0.28)	0.08

[a] Structure coefficients are in parentheses

are considered poor, and loadings below 0.32 are not interpreted (Comrey and Lee 1992). The two factors were moderately correlated at 0.52. This indicates a moderate relationship between the two factors and justifies the use of an oblique, rather than an orthogonal rotation (Tabachnick and Fidell 2001).

Communalities are the proportion of each item's variance that can be explained by the factors. Final communality estimates ranged from 0.08 to 0.69. Some of these values are low, which indicates some heterogeneity among the variables. That is, some variables are not as highly related to the factor as are others with higher communality estimates. In addition, lower communality estimates indicate a lower replicability of the factor structure.

The factor solution indicates that Nano-Motivation can be considered a separate construct from Nano-Awareness and Nano-Exposure, although the constructs are moderately related. The subscales of Nano-Awareness and Nano-Exposure are similar enough to be considered a single construct. This makes sense because being aware of nanotechnology probably means that one has also been exposed to nanotechnology.

Discussion

The purpose of this study was to develop an instrument that is capable of measuring student awareness of, exposure to, and motivation for, and knowledge of nanotechnology. This was accomplished through an iterative instrument development process involving the administration of Version 1 of the instrument followed by item and factor analyses. Revisions to the first instrument resulted in Version 2 of the *Nanotechnology Awareness Instrument*, which consists of three subscales: Nano-Awareness, Nano-Exposure, and Nano-Motivation. This version of the instrument appears to show promise as a valid and reliable indicator of student awareness of, exposure to, and motivation for nanotechnology that is capable of detecting changes over time.

From the first to the second implementation, several changes were made to the instrument to improve its psychometric properties as well as to provide more information about how the concepts of nanotechnology awareness, exposure, and motivation are related. For the Nano-Awareness subscale, no changes were deemed necessary because of the high level of internal consistency and the single-construct factor analysis. For the Nano-Exposure subscale, the only change that was made was to modify the format of the items to a Likert-type scale response. This format provides increased information about self-reported levels of exposure to nanotechnology in addition to allowing for additional item analyses. The Nano-Motivation subscale was also revised to a Likert-type format for the same reasons. In addition, this subscale was revised to be modeled after an existing motivation scale, the AIMS. The AIMS is theoretically based on four types of intrinsic motivators and was thought to provide better construct validity for the Nano-Motivation subscale.

The Nano-Knowledge subscale was dropped from the instrument. One of the challenges in creating this subscale is the identification of appropriate items. As a new and very interdisciplinary field, there is little consensus on what constitutes fundamental nanotechnology knowledge. Therefore, there is little consistency in the presentation of basic facts and topics in an introductory nanotechnology educational intervention. This has tended to force the creation of intervention-specific knowledge items that do not transfer well from one intervention to the next. The field will need to mature to enable the selection of items that span introductory to advanced knowledge in a meaningful and accepted way. It is suggested that a knowledge section be constructed individually based on the specific intervention or program.

The three subscales appear to be reliable measures of the constructs of awareness, exposure, and motivation. Internal consistency reliability was high for the subscales of Nano-Awareness, Nano-Exposure, and Nano-Motivation.

Exploratory factor analysis was used to examine the construct validity of the instrument. The factor analysis confirmed that motivation towards nanotechnology is a separate construct from awareness and exposure to nanotechnology. That is, although a student may have an awareness and thus exposure to nanotechnology, they may still not be motivated to pursue nanotechnology-related activities. Nano-Awareness and Nano-Exposure items may be combined into a single scale because the factor analysis indicates that they may be measuring a single construct.

One limitation of this study is the lack of post-intervention results to compare with pre-intervention results for the Version 2 implementation. Unfortunately, there were logistical and administrative constraints on administering the instrument again in AGR 101 and there was not a significant nanotechnology intervention in ENGR 100. Such results are needed to provide further evidence of the instrument's capability of showing significant pre-to post differences.

Results may not be generalizable because of the convenience sampling method. Future studies are needed to replicate these results and increase generalizability.

Conclusions

The *Nanotechnology Awareness Instrument* provides a means to evaluate nanotechnology educational interventions by using subscales designed to measure various facets of undergraduate students' awareness of, exposure to, and motivation for nanotechnology. Designing ways in which to effectively recruit undergraduates into the field of nanotechnology is a challenge that many universities are facing. An instrument that provides a valid and reliable way to assess interventions, courses, and programs is a valuable tool in identifying effective curricular strategies to motivate students to pursue nanotechnology as a field of study and career.

One practical implication of this instrument is that it allows for detecting whether a particular intervention or program is affecting motivation to pursue further studies of nanotechnology. The instrument can also be used to track students into appropriate coursework by examining the levels of exposure to, awareness of, or motivation to pursue nanotechnology.

Nanotechnology is quickly moving from the college to the K-12 level so that students are exposed to nanotechnology earlier. The National Center for Teaching and Learning (NCLT) is developing pilot nanotechnology modules for K-12 teachers to field-test in the classroom and is planning to expand the modules into curricula (National Nanotechnology Initiative 2007). Several nanotechnology teaching materials for the K-12 level have already been developed. For example, a nanotechnology presentation and student exercises about manipulating nano-scale matter was developed at an NCLT workshop by El Paso High School teachers for students at the junior high school level (Gardner 2006). The *Nanotechnology Awareness Instrument* may be useful for K-12 teachers who want to determine pre–post awareness and exposure to nanotechnology and how to affect student motivation to pursue further study in nanotechnology. Additionally, teachers may gain more awareness and insight about students' levels of nanotechnology exposure and may choose to include more nanotechnology concepts in the curriculum.

This instrument was designed for use before and after an intervention or program so that changes over time may be assessed. This comparison will permit the evaluation of nanotechnology educational interventions. Recommendations include using the instrument with a variety of students and courses and with other interventions designed to encourage interest in nanotechnology. Data from these populations and settings will help establish the utility of the survey as well as further establish the psychometric characteristics of the instrument.

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Appendix

Nanotechnology Awareness Instrument—Version 2

For the following items, please indicate the extent to which you agree or disagree using the following scale: Strongly disagree, disagree, neutral, agree, or strongly agree.

What is your awareness of nanotechnology? I can:

(1) Name a nanoscale-sized object.
(2) Describe one way nanotechnology directly impacts my life.
(3) Name a field of study that currently conducts nanotechnology research.
(4) Describe one way nanotechnology may benefit society/humankind.
(5) Name an application of nanotechnology.
(6) Describe a process to manufacture objects at the nanoscale.
(7) Name an instrument used to make measurements at the nanoscale.
(8) Describe one way nanotechnology may directly impact my life in the future.

What is your motivation to investigate nanotechnology? I plan to:

(1) Read a fiction story about nanotechnology.
(2) Formally teach nanotechnology concepts (e.g., as a teaching assistant).
(3) Investigate the implications of nanotechnology.
(4) Informally/casually teach someone something about nanotechnology.
(5) Seek information about internships or Co-op experiences with companies engaged in nanotechnology.
(6) Read a news story or popular magazine article about nanotechnology.
(7) Give a presentation related to nanotechnology to an audience I perceive as having more experience with nanotechnology than I.
(8) Read a research journal article about nanotechnology.
(9) Enroll in a course about nanotechnology.
(10) Attend a non-course related seminar about nanotechnology.
(11) Visit an industry or business that specializes in nanotechnology.
(12) Give a presentation related to nanotechnology to an audience I perceive as having less experience with nanotechnology than I.
(13) Watch a program about nanotechnology.
(14) Apply or interview for a nanotechnology related work or research experience.
(15) Investigate fields of study in which I can learn more about nanotechnology.

(16) Obtain a work experience or undergraduate research opportunity related to nanotechnology.

For the following items, please indicate the extent to which you have participated in each activity using the following scale: Not at all/never, very little, sometimes/occasionally, a fair amount, or a great deal.

What is your exposure to nanotechnology? I have:

(1) Heard the term nanotechnology.
(2) Read [something] about nanotechnology.
(3) Watched a program about nanotechnology.
(4) Had one [or more] instructors/teachers talk about nanotechnology in class.
(5) Participated in an activity involving nanotechnology [lab, project,…].
(6) Taken a class about nanotechnology.

When you hear the term nanotechnology, what length-scale "typically" comes to mind?

(1) 10^9 m
(2) 10^6 m
(3) 10^3 m
(4) 10^1 m
(5) 10^{-1} m
(6) 10^{-3} m
(7) 10^{-6} m
(8) 10^{-9} m
(9) None of the above

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