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Perceptions of Nanotechnology by Undergraduate Students in Some Nigerian Universities

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Abstract

Advances in nanotechnology has brought about development of cutting–edge technologies in various industries in technologically developed countries. However, little is known about its risks and potential applications in the developing countries around the world. This study investigates awareness, risk and benefit perceptions of nanotechnology by undergraduate students from some universities in Nigeria. The undergraduate students' perceptions and opinions about nanotechnology were elicited through a survey tool that comprise of 30 structured questions. The study was carried out among 110 respondents from both public and private universities distributed within the four geopolitical zones in Nigeria. The results showed that a greater percentage (62.3%) of respondents had little to no understanding of the context or basic knowledge of nanotechnology and only (37.7%) of respondents had basic knowledge of nanotechnology. Although a majority (77.4%) of respondents had some level of awareness of the word 'nanotechnology', their perceptions of the risks and benefits associated with the technology was poor. This study suggests that effective understanding of perceptions of nanotechnology by the undergraduate students is critically important for realization of technological advances in a developing country like Nigeria.Therefore, there is an urgent need to educate the future workforce about this emerging and rapidly growing field of nanotechnology and its diverse applications.

Keywords: *nanotechnology, nanomaterial, perception, undergraduate students, universities, Nigeria*

Introduction

The developments of nanoscience and nanotechnology has brought about rapid advances in cutting–edge research, technological innovation and economic growth around the world. However, there are several potential human health, societal and environmental implications associated with nanotechnology and its applications. Nanotechnology is the study of design, synthesis, characterization, production and application of materials and/or systems using ultrafine particles (nanoparticles) that can be used across various scientific and technical fields at nanoscale. At this dimensional scale, nanoparticles are substances of nanometer (nm) sizes (10^{-9} m) (Goebelbecker and Albrecht, 2014; Varadan et al., 2010; Besley, 2010). The novel and enhanced properties of nanoparticles (such as large surface area compared to their volume/mass, higher strength, increased control of light spectrum, light weight, electrical conductivity and greater chemical reactivity) (Varadan et al., 2010) has resulted in unbound possibilities and made nanotechnology to support wider applications in today's society. Recent advances and development of nanotechnology has resulted in diverse applications in various sectors as follows:

- Environment: Environmental management (Shah, 2014; Hull et al., 2014), environmental treatment and remediation (Theron et al., 2008; Grieger et al., 2010)
- Medicine: disease detection for preventive treatment (Srinivas et al., 2000; Mansoori et al., 2007), advanced medical treatment (Shah, 2014; Nie et al., 2007; Morris et al., 2014; Roco, 2003)
- Food industry: packaging and safety (Duncan, 2011)
- Material science: nano-material for automobile and aerospace industries (Gohardani et al., 2014; Haynes and Asmatulu, 2013; Swingler, 2013), monitoring devices (Vaseashta and Malinovska, 2005) and corrosion prevention (Adlakha-Hutcheon et al., 2009).

- Sustainable energy (Serrano et al., 2009), power generation and waste heat recovery systems (Bell 2008)
- Petroleum exploration and production (Ponmani et al., 2013), crude oil processing (Bjorgen *et al*., 2008) and enhanced oil recovery (Ogolo *et al*., 2012).

Nanotechnology is already applied in many computing, communications, electronics systems and there are several applications of nano-technology around the world.

In response to the rapid development of nanotechnology, many countries around the world have added nano-technology to the science curricula from elementary school to university level in order to enhance student understanding of this rapidly growing and important field (Dyehouse et al., 2008; Lin et al., 2015). Although the introduction of nanoscience and nanotechnology into school education have been reviewed (Hingant and Albe, 2010; Ghattas and Carver, 2012; Jones et al., 2013), most people are yet to fully understand the potential capabilities of nanotechnology and its products (Hull et al., 2014). Over the years, four generations of nanotechnology products and processes (passive nano, active nano, integrated nano and molecular nano–systems) have been predicted (Renn and Roco, 2006). The risks and benefits attributed to nanotechnology have been examined (Siegrist, 2010; Siegrist et al., 2007; Handy and Shaw, 2007) and the global implications of nanotechnology have been extensively explained (Aluya, 2015). Although adult's public perception and attitudes have been widely studied (Besley, 2010; Morris et al., 2014; Siegrist, 2010; Simonneaux et al., 2011; Smith et al., 2008), there is paucity of information on the attitudes of young people, especially their knowledge about and perceptions of nanotechnology in several developing countries around the world.

This study sought to investigate undergraduate students' awareness, opinions and perceptions of nanotechnology in some universities in Nigeria. This research was guided by the following questions:

(i) What are undergraduate students' perceptions of the risks and benefits associated with nanotechnology applications?

(ii) Does undergraduate students' understanding of nanotechnology relate to their risks and benefits perceptions of nanotechnology and its applications?

Understanding of perceptions of nanotechnology amongst undergraduate students is important because tertiary institutions are the platform in which scient knowledge of risk assessment and conc perceptions about emerging technologies likely to be formed.

Methods

Participants

Participants were drawn from a population of undergraduate students from nineteen (19) universities between August and October 2013. The total number of the participants (undergraduate students) included in the sampling was N = 150, of which 110 questionnaires were retrieved and only 106 questionnaires were duly completed/valid for this study. In the context of this study, an undergraduate student is a student who is studying for his/her first degree (usually BA, BSc or BEng) program enrolled for within the specified duration of the study. In order to capture a representative sample of undergraduate levels, the participants were sourced from year one through final year from some public and private universities within the four geopolitical zones in Nigeria.

Instrument and Data Collection

In order to determine the undergraduate students' awareness, opinions and perceptions of nanotechnology in some universities in Nigeria, a questionnaire consisting of 30 structured questions was developed based on some published literature (Dyehouse *et al.*, 2008; Lin *et al*., 2013; Macoubrie, 2006). In line with the background information, the questionnaire was divided into two sections (Section A: Respondent's bio-data and Section B: Respondent's perception of nanotechnology) and further scrutinized for clarity of purpose to enhance undergraduate students understanding of the research topic. The questionnaire started with Section A, in which the respondents were given a short list of demographics items: age, sex, married status, name of university, university location, location of residence, religion, level or year of study and area of study. In the Section B of the questionnaire, the first item on the assessment asked the students whether they have ever heard of the term 'nanotechnology' before now. This item was

intended to establish a baseline measure of whether students have any prior basic knowledge or understanding about nanotechnology. Several survey items evaluated the construct of student interest in nanotechnology and a combination of scales was employed including mostly: Agree, disagree and cannot say; to assess the perception of nanotechnology by the undergraduate students. 150 copies of questionnaires were randomly distributed to undergraduate students during the commencement of the long holiday and out of the 110 copies retrieved, only 106 completed copies were valid for the study.

Data Analysis

In the analysis of the data, a preliminary analysis of variance of the surveys was conducted to determine any significant differences in students' perceptions of nanotechnology. Most of the analyses presented in this study are descriptive and interpretative statistical methods. Among the statistical methods, frequencies (f) and percentages (%) were employed in data presentation and results discussion (Mansoori et al., 2007). All analyses were performed using SigmaPlot® (Version 12.5, Systat Software Inc.).

Results

Demographics of the Respondents

The respondents were spread across various states within the four geopolitical zones (north-central, south-south, south-east and south-west) and demographics of the participants are shown in Table 1. The universities that were involved in the survey are as follows: Cross River State University of Technology (CRUTECH) 16.0%, University of Calabar (UNICAL) 26.4%, Rhema University 31.1%, University of Port Harcourt (UNIPORT) 1.9%, Benue State University 0.9%, Imo State University (IMSU) 1.9%, University of Uyo (UNIUYO) 2.8%, Veritas University 0.9%, Abia State University (ABSU) 4.7%, Federal University of Technology Owerri (FUTO) 0.9%, University of Lagos (UNILAG) 1.9%, University of Benin (UNIBEN) 0.9%, Madonna University 0.9%, University of Abuja 0.9%, Ladoke Akintola University of Technology 0.9%, Olabisi Onabanjo University 0.9%, University of Nigeria Nsukka (UNN) 3.8%, Enugu State University of Technology (ESUT) 0.9%, and Michael Okpara University of Agriculture 0.9%.

Based on the data retrieved, majority (60.4%) of respondents were females and 38.7% were males while 0.9% represent respondent with unknown sex. A greater percentage (84.9%) of the undergraduate students were in the ages 18 – 25 category, ages 26 – 35 category was 13.2% and ages category > 36 was 1.9%. A greater percentage (92.5%) of the undergraduate students was single, 2.8% were married and 4.7% represents students with unknown marital status. From the results obtained, 30.2% of the respondents were 100 level, 200 level (23.6%), 300 level (18.9%), 400 level (16.9%), 500 level (5.7%) and 4.7% represent respondents with unknown level of education. Percentage of respondents studying various courses are as follows: Social Science (22.6%), Management (7.5%), Medicine (6.6%), Engineering (9.4%), Science (45.3%), Arts (3.8%), Education (2.8%) and 1.9% represent respondents with unknown study area.

Perception of Nanotechnology

Perception of 'Nanotechnology' by the undergraduate students who participated in this survey are presented in Table 2. In this study, a majority (62.3%) of respondents had never heard of the term 'Nanotechnology' and only 37.7%) of respondents had basic knowledge of nanotechnology. As such, young people's perception of nanotechnology could be influence by various applications in question and their readiness or willingness to learn beyond their course of study. Although > 18.9% of respondents did not know that nanotechnology deals with processes that take place on nanometer scale from 1 – 100 nm, 33.9% of respondents had basic knowledge that nanotechnology is a 21st century technology while 3.8% of respondents disagree. However, 62.3% of respondents were unable to decide whether it is a 21st century technology and this further show that they had no basic or contextual knowledge of the technology. This study found that only 25.5% of respondents are attentive to national and global technology advancements, however, a majority (63.2%) of respondents are not very attentive while 11.3% are never attentive at all. Therefore, it could be concluded that the undergraduate students are rather only focused on their specific course of study without recourse to other courses that may advance their technological know-how during the period of their study.

In this study, the results showed that most undergraduate students were not familiar with the subject matter and > 60.0% of respondents did not know where nanotechnology can be applied. However, about 31.1% of respondents had some level of basic knowledge about where the current technology can be applied and 3.8% of respondents were unable to answer questions relating to applications of nanotechnology. Although 51.9% of respondents were undecided in terms of area of nanotechnology applications, > 36.8% of respondents believe the technology can be applied in agriculture and medicine, respectively. This study found that the majority (66.9%) of respondents had no basic knowledge of the term 'nanotechnology' and that 33.1% had the basic knowledge or understanding of the term. The data obtained in this study further support that fact that 31.1% of respondents had the basic knowledge of nanotechnology as well as area of application of nanotechnology in the society.

Although the majority (70.8%) of respondents expressed unclear or negative opinions, 19.8% of respondents agree while 9.4% of respondents disagree on the use of nanotechnology in making cost effective high quality product. In addition, the majority (65.3%) of respondents were undecided in referring to nanotechnology as a clean technology, only 30.0% agree that it's a clean technology and 4.7% could not consider nanotechnology as a clean technology. In this study, a majority (67.9%) of respondents had no idea about the use of nanotechnology in sustainable problems solving, however, 29.2% of respondents agree and only 1.9% of respondents disagree. In addition, the majority (> 50.0%) of respondents had no basic knowledge of nanotechnology as an exponential technology and only 6.6% disagrees while 3.8% of respondents were undecided. However, 30.1% of respondents considered nanotechnology as an exponential technology. Although 10.4% of respondents had positive responses, 16.0% exhibited negative response and a majority (72.6%) of respondents with unclear opinions are not sure if nanotechnology will endanger our health and environment in the long term. Although some of the undergraduate students had positive emotions towards nanotechnology in terms of its usefulness, most of those having unclear or negative opinions of nanotechnology view its risks and benefits as equal.

Attitudes and opinions play an important role in the determination of perceptions of people towards any field of science and technology. In this study, respondents' knowledge of nanoparticles (Tables 3) and respondents' attitude towards nanomaterials and products (Table 4) were captured in the questionnaires.

This study found that 28.3% of respondents had basic knowledge of nano-particles and a majority (71.7%) of the undergraduate students had no basic knowledge or understanding of nano-particles. Although the majority (92.5%) of respondents lack basic understanding and risks assessment/control measures, only 7.5% of the respondents were aware of any existing assessment as well as regulatory framework (Table 3). This study also seeks to define attitude as a risk–benefit equation and how undergraduate students differentially perceived the risks and benefits of various nanotechnology applications (Table 4). From the results obtained, a majority (> 56%) of respondents expressed unclear or negative opinion about nanomaterials and its products. Although most of the students were having unclear or negative emotions towards nanotechnology, majority (> 80%) of respondents expressed positive interest and willingness to learn about nanotechnology and its applications. This study found that the majority (77.4%) of respondents had some level of awareness of 'nanotechnology', however, their perceptions of the risks and benefits associated with the technology was poor.

Table 1: Profile of respondent undergraduates

Parameters	Frequency	Percentage (%)
(1) Age		
16-25	90	84.9
26-35	14	13.2
>36	2	1.9
(2) Gender		
Male	41	38.7
Female	64	60.4
Unknown	1	0.9
(3) Marital status		
Single	98	92.5
Married	3	2.8
Unknown	5	4.7
(4) Universities/ location (state)		
Rhema University (Abia)	33	31.1
UNICAL (Cross River)	28	26.4
CRUTECH (Cross River)	17	16.0
UNIPORT (Rivers)	2	1.9
Benue State University (Benue)	1	0.9
IMSU (Imo)	2	1.9
UNIUYO (Akwa Ibom)	3	2.8
Veritas University (Abuja)	1	0.9
ABSU (Abia)	5	4.7
FUTO (Imo)	1	0.9
UNILAG (Lagos)	2	1.9
UNIBEN (Benin)	1	0.9
Madonna University (Anambra)	1	0.9
University of Abuja (Abuja)	1	0.9
Ladoke Akintola University of Technology	1	0.9
Olabisi Onabanjo University (Ogun)	1	0.9
UNN (Enugu)	4	3.8
ESUT (Enugu)	1	0.9
Michael Okpara University of Agriculture	1	0.9
(5) Educational level		
100	32	30.2
200	25	23.6
300	20	18.9
400	18	16.9
500	6	5.7
Unknown level	5	4.7
(6) Area of Study		
Science	48	45.3
Social science	24	22.6
Engineering	10	9.4
Management	8	7.5
Medicine	7	6.6
Arts	4	3.8
Education	3	2.8
Unknown	2	1.9

Table 2: Perception of nanotechnology (n = number of positive response)

Topics	N	%
1. Have you ever heard of the term nanotechnology?	40	37.7
2. Nanotechnology deals with processes that take place on the nanometer scale from 1-100 nm	20	18.9
3. Nanotechnology is said to be a 20th century technology.	36	33.9
4. Do you know where nanotechnology can be applied?	33	31.1
5. Nanotechnology involves making high quality products at very low cost.	21	19.8
6. Nanotechnology can be referred to as a clean technology.	35	33.0
7. Nanotechnology can help alleviate sustainability problems.	31	29.2
8. Do you agree that nanotechnology is an exponential technology?	32	30.1
9. Do you think that nanotechnology will endanger our health and environment in the long term?	11	10.4
10. Please rate the word nanotechnology in terms of its awareness, from generally known to unknown.	29	27.4

Table 3: Respondents knowledge of nanoparticles (n= number of positive response)

Topics	n	%
1. Nanoparticles are.....		
Very big	3	2.8
Small	16	15.1
Not seen with an unaided eye	30	28.3
Cannot say	52	49.1
2. Are you aware of any regulatory framework that assess and control risks associated with the release of nanoparticles?		
Yes	8	7.5
No	49	46.2
Cannot say	49	46.2

Table 4: Respondents attitude towards nanomaterials and its products (in %, n= 106)

Topics	Agree	Disagree	Cannot say
1. Nano-materials and products can be produced without harming the environment or human health.	20.8	15.1	63.2
2. Some nano-materials may have unintended consequences on human health and the environment.	36.8	4.7	58.5
3. Most nano-materials are produced by chemical processes.	33.9	6.6	56.6

In general, there was no significant relationship between undergraduate students' level of awareness of nanotechnology and their perceptions of the risks and benefits associated with the technology.

Discussion

This study was conducted to achieve a better understanding of undergraduate students' level of awareness and perceptions of the risks and benefits of nanotechnology and its applications. In comparison to findings by other researchers (Macoubrie, 2006; Parr, 2005; Scheufele and Lewenstein, 2005), the present study revealed that the majority (77.4%) of respondents had some level of awareness of the word 'nanotechnology' even though their perceptions of the risks and benefits associated with the technology was poor. Previous studies

conducted in other locations (Kahan et al., 2007; Pidgeon and Rogers-Hayden, 2007) showed that the majority of respondents had little or no knowledge of nanotechnology. Some laypeople who had any knowledge rather perceived more risks in it than the benefits (Siegrist et al., 2007). Some informed citizens and the general public expressed low trust in the government to manage the risks associated with it (Macoubrie, 2006). Furthermore, it is pertinent to note that most public attitudes towards emerging technologies is influenced by insufficient relevant scientific information as well as some mass media misinformation. These factors seem to further influence public support and funding in such areas of research (Scheufele and Lewenstein,, 2005). In this present study, some of the undergraduate students have heard about the word 'nanoscience' and/or 'nanotechnology' but not the meaning of the term 'nanotechnology'. Although the proportion of people with low level of knowledge of nanotechnology in some technologically developed countries seems to be decreasing rapidly, there is low level of knowledge and poor perception of nanotechnology amongst undergraduate students in Nigeria.

Perceptions of the risks associated with emerging technology is a critical component of the formation of students' attitudes toward technology. This study found that the majority (> 70%) of the undergraduate students had no basic knowledge or understanding of nanotechnology and its applications. The adverse effects of potential human exposure to nanomaterial and its fate in the environment have been widely recognized around the world. Studies have shown that people have concerns especially about the long-term effects of nanotechnology (Besley, 2010) and the potential use of nanotechnology devices for surveillance (Lin et al., 2013). According to Cobb and Macoubrie (2004), the majority (60%) of the USA citizens exhibit a low level of trust in leaders concerning minimizing nanotechnology risks on humans also, they view its contribution to the development of new weapons and losing personal privacy as perils. Therefore, risk perception could be further complicated by the fact that nanotechnology can be applied in various ways depending on the product or application (Lin et al., 2013).

The results of this study might have been complicated by the fact that individuals may have a singular perception of the risk of nanotechnology when surveyed. Depending on the group of people involved in data gathering during the survey, it is important to note that there are different attitudes as well as perception of risk associated with different applications of nanotechnology. This present study found that the majority (72.6%) of respondents with unclear opinions are not sure if nanotechnology will endanger our health and environment in the long term. However, most of respondents that expressed unclear or negative opinions of nanotechnology see its risks and benefits as equal. It is widely suggested that if people have more knowledge and understanding about any emerging technology, they would have more positive attitudes towards its products.

This present study found that although the majority (77.4%) of respondents had some level of awareness of 'nanotechnology', there was no significant relationship between undergraduate students' level of awareness of and their perceptions of the risks and benefits associated with nanotechnology. According to Lee et al. (2005), lack of proper understanding on the part of the general public does not necessarily mean that they will not form negative attitudes about these new technologies. However, people may tend to use cognitive ideological predispositions or cues from mass media, to form judgments about emerging technologies. In this present study, although the undergraduate students appeared to have low level of knowledge and poor perceptions of technology, their understanding does not translate to how they viewed potential risks and benefits of nanotechnology.

Although there is poor risk–benefit perception in this study, the results obtained suggest that there is high level of students' willingness to be acquainted with this emerging technology given the opportunity. In addition, results have further shown that there is no simple link between factual scientific knowledge and the acceptance of nanotechnology. However, public perception of nanotechnology and an effective assessment framework involved in its application may influence the realization of nano-technological advances (Siegrist et al., 2007).

Conclusion

The results obtained in this study lay the groundwork for future exploration into the best approach for understanding undergraduate students' as well as public perception of nano-technology in Nigeria. The results obtained in this study also support previous findings by other researchers and the educational significance of this survey revealed low level of knowledge about nano-technology amongst undergraduate students in tertiary institutions in Nigeria. Although this study adopted some close ended questions, there is a need to introduce some open ended questions and/or statements like 'please comment on your view of nano-technology' in the future studies in order to have wider knowledge of people's perception. Nanotechnology is an emerging and rapidly growing field whose advancements and prospects pose many great challenges not only to scientists and engineers, but also to society at large. Our deductions are in agreement with those reported in Hingant and Albe, (2010) that 'nano-literacy' should be designed and integrated into educational curriculum from kindergarten to the tertiary institution in order to improve student's understanding of nanoscale. This study suggests that effective understanding of emerging trends in undergraduate students' perceptions of nano-technology is critically important for realization of technological advances in a developing economy like Nigeria. Therefore, there is an urgent need to educate the future workforce about this emerging and rapidly growing field of nano-technology and its applications. In addition, information gathered from this study can be used by researchers in various areas of nano-technology applications for the development of adequate training, capacity building and research development.

References

Adlakha-Hutcheon, G.; Khaydarov, R.; Korenstein,R.; Varma, A.; Vaseashta,H.; A. Stamm,H.; Abdel-Mottaleb,M. (2009). "Nanomaterials, nanotechnology," *Nanomaterials: Risks and Benefits*, Springer, pp. 195-207

Aluya, J. (2015). Nanotechnology Implications and Global Leadership Perspectives. *Energy Sources, Part B: Economics, Planning, and Policy*,*10*(1), 31-37.

Bell, L. E. (2008). Cooling, heating, generating power, and recovering waste heat with thermoelectric systems. *Science*, *321*(5895), 1457-1461.

Besley, J. (2010). Current research on public perceptions of nanotechnology. *Emerging Health Threats Journal*, *3*, 1-25

Bjørgen, M.; Joensen, F.; Holm, M. S.; Olsbye, U.; Lillerud, K. P.; Svelle, S. (2008). Methanol to gasoline over zeolite H-ZSM-5: Improved catalyst performance by treatment with NaOH. *Applied Catalysis A: General*, *345*(1), 43-50.

Cobb, M.D. and Macoubrie, J. (2004). Public perceptions about nanotechnology: risks, benefits, and trust. *Journal of Nanoparticle Research 6*, 395-405 004.

Duncan, T. V. (2011). Applications of nanotechnology in food packaging and food safety: barrier materials, antimicrobials and sensors. *Journal of Colloid & Interface Science*, *363*(1), 1-24.

Dyehouse, M. A.; Diefes-Dux, H. A.; Bennett, D. E.; Imbrie, P. K. (2008). Development of an instrument to measure undergraduates' nanotechnology awareness, exposure, motivation, and knowledge. *Journal of Science Education and Technology*, *17*(5), 500-510.

Ghattas, N. I. and Carver, J. S. (2012). Integrating nanotechnology into school education: a review of the literature. *Research in Science & Technological Education*, *30*(3), 271-284.

Goebelbecker, J. and Albrecht, E. (2014). VSS Where Formal Regulations are Missing: Potential Study on Example of Nanotechnologies. In *Voluntary Standard Systems*. Springer Berlin Heidelberg, pp. 77-97

Gohardani, O.; Elola, M. C.; Elizetxea, C. (2014). Potential and prospective implementation of carbon nanotubes on next generation aircraft and space vehicles: A review of current and expected applications in aerospace sciences. *Progress in Aerospace Sciences*, *70*, 42-68.

Grieger, K. D.; Fjordbøge, A.; Hartmann, N. B.; Eriksson, E.; Bjerg, P. L.; Baun, A. (2010). Environmental benefits and risks of zero-valent iron nanoparticles (nZVI) for in situ remediation: risk mitigation or trade-off? *Journal of Contaminant Hydrology*, *118*(3), 165-183.

Handy, R. D. and Shaw, B. J. (2007). Toxic effects of nanoparticles and

nanomaterials: implications for public health, risk assessment and the public perception of nanotechnology. *Health, Risk & Society*, *9*(2), 125-144.

Haynes, H.; Asmatulu, R. (2013) "Chapter 7 - Nanotechnology Safety in the Aerospace Industry," *Nanotechnology Safety*, Asmatulu, R. (ed.) Amsterdam: Elsevier, pp. 85-97

Hingant, B. and Albe, V. (2010). Nanosciences and nanotechnologies learning and teaching in secondary education: A review of literature. *Studies in Science Education*, *46*(2), 121-152.

Hull, M. S.; Quadros, M. E.; Born,R.; Provo, J.; Lohani,V. K.; Mahajan, R. L. (2014.) "Chapter 16 - Sustainable Nanotechnology: A Regional Perspective," In *Nanotechnology Environmental Health and Safety (Second Edition)*, Hull, M. S. and Bowman,D. M. (eds.), Oxford: William Andrew Publishing, pp. 395-424

Jones, M. G.; Blonder, R.; Gardner, G. E.; Albe, V.; Falvo, M.; Chevrier, J. (2013). Nanotechnology and nanoscale science: Educational challenges. *International Journal of Science Education*, *35*(9), 1490-1512.

Kahan, D. M.; Slovic, P.; Braman, D.; Gastil; J.; Cohen,G. L. (2007) "Affect, values, and nanotechnology risk perceptions: an experimental investigation," *GWU Legal Studies Research Paper* (261).

Lee, C. J.; Scheufele, D. A.; Lewenstein, B. V. (2005). Public attitudes toward emerging technologies examining the interactive effects of cognitions and affect on public attitudes toward nanotechnology. *Science Communication*, *27*(2), 240-267.

Lin, S. F.; Chen, J. Y.; Shih, K. Y.; Wang, K. H.; Chang, H. P. (2015). Science teachers' perceptions of nanotechnology teaching and professional development: a survey study in Taiwan. *Nanotechnology Reviews*, *4*(1), 71-80.

Lin, S. F.; Lin, H. S.; Wu, Y. Y. (2013). Validation and exploration of instruments for assessing public knowledge of and attitudes toward nanotechnology. *Journal of Science Education and Technology*, *22*(4), 548-559.

Macoubrie, J. (2006). Nanotechnology: public concerns, reasoning and trust in government. *Public Understanding of Science*, *15*(2), 221-241.

Mansoori, G. A.; Mohazzabi, P.; McCormack, P.; Jabbari, S. (2007). Nanotechnology in cancer prevention, detection and treatment: bright future lies ahead. *World Review of Science, Technology and Sustainable Development*, *4*(2), 226-257.

Morris, S. A.; Farrell, D.; Grodzinski, P. (2014). Nanotechnologies in cancer treatment and diagnosis. *Journal of the National Comprehensive Cancer Network*, *12*(12), 1727-1733.

Nie, S.; Xing, Y.; Kim, G. J.; Simons, J. W. (2007). Nanotechnology applications in cancer. *Annu. Rev. Biomed. Eng.*, *9*, 257-288.

Ogolo, N. A.; Olafuyi, O. A.; Onyekonwu, M. O. (2012). Enhanced oil recovery using nanoparticles. In *SPE Saudi Arabia Section Technical Symposium and Exhibition*. Society of Petroleum Engineers.

Parr, D. (2005). Will nanotechnology make the world a better place?. *Trends in Biotechnology*, *23*(8), 395-398.

Pidgeon, N., and Rogers-Hayden, T. (2007). Opening up nanotechnology dialogue with the publics: risk communication or 'upstream engagement'?.*Health, Risk & Society*, *9*(2), 191-210.

Ponmani, S.; Nagarajan, R.; Sangwai, J. (2013). Applications of Nanotechnology for Upstream Oil and Gas Industry. *Journal of Nano Research 24*, 7-15.

Renn, O. and Roco, M. C. (2006). Nanotechnology and the need for risk governance. *Journal of Nanoparticle Research*, *8*(2), 153-191.

Roco, M. C. (2003). Nanotechnology: convergence with modern biology and medicine. *Current Opinion in Biotechnology*, *14*(3), 337-346.

Scheufele, D. A, and Lewenstein, B. V. (2005). The public and nanotechnology: How citizens make sense of emerging technologies. *Journal of Nanoparticle Research*, *7*(6), 659-667.

Serrano, E.; Rus, G.; Garcia-Martinez, J. (2009). Nanotechnology for sustainable energy. *Renewable and Sustainable Energy Reviews*, *13*(9), 2373-2384.

Shah, M. A.; Bhat, M. A.; Davim, J. P. (2015). *Nanotechnology applications for improvements in energy efficiency and environmental management*.

Siegrist, M. (2010). Predicting the future: Review of public perception studies of

nanotechnology. *Human and Ecological Risk Assessment*, *16*(4), 837-846.

Siegrist, M.; Keller, C.; Kastenholz, H.; Frey, S.; Wiek, A. (2007). Laypeople's and experts' perception of nanotechnology hazards. *Risk Analysis*, *27*(1), 59-69.

Simonneaux, L.; Panissal, N.; Brossais, E. (2013). Students' perception of risk about nanotechnology after an SAQ teaching strategy. *International Journal of Science Education*, *35*(14), 2376-2406

Smith, S. E. S.; Hosgood, H. D.; Michelson, E. S.; Stowe, M. H. (2008). Americans' nanotechnology risk perception. *Journal of Industrial Ecology*, *12*(3), 459-473.

Srinivas, P. R.; Barker, P.; Srivastava, S. (2002). Nanotechnology in early detection of cancer. *Laboratory Investigation*, *82*(5), 657-662.

Swingler, J. (2013). "1 - MEMS for passenger safety in automotive vehicles," In *Mems for Automotive and Aerospace Applications*, Kraft M. and White,N. M. (eds.), Woodhead Publishing, pp. 3-28

Theron, J.; Walker, J. A.; Cloete, T. E. (2008). Nanotechnology and water treatment: applications and emerging opportunities. *Critical Reviews in Microbiology*, *34*(1), 43-69.

Varadan, V. K.; Pillai, A. S.; Mukherji, D.; Dwivedi, M.; Chen, L. (2010). *Nanoscience and nanotechnology in engineering*, World Scientific, pp. 50-51

Vaseashta, A.; Dimova-Malinovska, D. (2005). Nanostructured and nanoscale devices, sensors and detectors. *Science and Technology of Advanced Materials*, *6*(3), 312-318.