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Students' Perception of Learning Experience of Risk Management for Nano-Scaled Materials

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PEER – REFEREED PERSPECTIVE

Students' Perception of Learning Experience of Risk Management for Nano-Scaled Materials

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ABSTRACT

As nanotechnology becomes increasingly prevalent in society (through workplace processes, consumer goods, and environmental exposures), there is a need to develop training programs to educate people in advanced material terminology, benefits, and adverse effects. Safety when handling nanomaterials is an important factor to sustain the viability of nanotechnology as a whole. Nanotechnology concepts can be communicated to students as its own subject matter or as an enabler in other STEM fields. Research has shown that offering courses in nanotechnology aids in educating and recruiting students into technology-oriented workforce and has the potential to enable innovations in the field for years to come. Here, we present the methods and outcomes of a departmental driven approach to proactively educate undergraduates in risk management of nanomaterials. The development of a 4000-level course called *Principles of Risk Management for Nano Scaled Materials* was introduced into the Industrial Technology program in 2009. The genesis for the course came from a funded National Science Foundation grant. Instructors performed surveys to ascertain the students' perceptions of course content. Survey results revealed that the majority of the students evaluated the course content as excellent, citing that they acquired new knowledge in STEM fields as the largest measurable outcome.

Introduction

Since the development of the Buckyball (C_{60}) in 1985, research in nanotechnology has made tremendous strides in the application of nanomaterials in cosmetics, agriculture, aerospace, and automotive industries. By the year 2020, an estimate of six million workers trained in nanotechnology and other advanced material techniques will be needed to produce, incorporate, transport, and use nanomaterial-enabled products worldwide; two million of which are expected to be employed within the United States (Roco, 2011). Engineers and technologists who work with engineered nanomaterials (ENMs) must understand the differences among the classes of various nanomaterials as well as the potential health and environmental hazards associated with each class. Furthermore, protective safety measures should be taught and enforced to help mitigate the onset of health hazards.

The estimated workforce in the field of nanotechnology is supported by the economic drivers demanding the use or inclusion of engineered nanomaterials in consumer products or industrial processes. The global nanotechnology financial outlook for 2020 could reach over $75 billion dollars (inclusive of both nanomaterials themselves as well as nan-enabled products), such as the use of nanotechnology processes or components in the electronics, energy, pharmaceutical, medical device, military and food industries (PR Newswire, 2015). With all the available application opportunities of nanotechnology, there is an inevitable probability that workers will interact with low-dose exposures and high-dose exposures of ENMs. Since the hazard, exposure, and risk literature are populated with thousands of studies reporting adverse human and environmental health effect data, workers ought to be protected when manufacturing nanomaterials. The manipulation of matter on the atomic scale produces new structures which potentially can lead to unknown exposures, hazards, and risks (NIOSH, 2016).

Current research suggests that low solubility nanoparticles can be more toxic than larger particles (NIOSH, 2016; Sager & Castranova, 2009). This finding is an example of some of the more complicated trends reported upon in the nanotoxicology literature and presents challenges in the education of workers. Safety Data Sheets (SDS) can provide pertinent data to protect workers by outlining risks and recommending personal protective equipment (PPE) use; however, there must also be a fundamental understanding of toxicology, physical science, and chemistry if workers are expected to identify and recognize hazards associated with engineered nanomaterials. Furthermore, training ought to be theoretical (through the classroom or online platforms) as well as actionable (through demonstrated training). Therefore, there is a need to become proactive and educate college students in the area of risk management of nanoparticles.

Even though nanotechnology in the workplace in still relatively new and not a component of traditional technology courses, the concepts that link nanoscience and environmental health and safety (EHS) must be introduced and implemented to both new and existing nanotechnology workforce educational materials. The National Institute of Occupational Safety and Health (NIOSH) has been on the forefront in supplying laboratory and field-based research related to the possible human health effects after exposure to nanoparticles. In an effort to communicate its recommendations, NIOSH published a guidance document entitled "Approaches to Safe Nanotechnology Managing the Health and Safety Concerns Associated with Engineered Nanomaterials" that stressed, "…nanomaterials present new challenges to [the] understanding, predicting, and managing [of] potential health risks to workers. As with any material being developed, scientific data on health effects in exposed workers are largely unavailable" (NIOSH, 2009, pg. 17). The World Health Organization (WHO) created evidence-based content to assist in educating workers on potential hazards of engineered nanomaterials (Safety and Health, 2018) which is quite similar to NIOSH's approach to educating workers on nanomaterial safety. Both organizations have determined that there is more research needed to investigate the long-term health effects in humans.

Risk Management of Nanomaterials

Before risk management can be implemented, a risk assessment must be completed. The most common obstacles in the human health risk assessment process is to define the hazard, determine if any regulation exists, and identify the guidance set to protect workers from risk. While many definitions of an engineered nanomaterial include at least one dimension being <100 nanometer in size, some particles outside of this strict size regime may also demonstrate unique physical, chemical, or biological properties, as well. Furthermore, many of the most recently designed advanced materials contain some type of nanomaterial component (Marchant & O'Conner, 2010). The other components of the risk assessment process include dose-response assessment and exposure assessment. Together, dose-response, hazard, and exposure aid in the characterization of risk; this process has been applied to engineered nanomaterials and other nanotechnology processes effectively.

A risk assessment can inform risk management processes. The earliest form of risk management was traditional and defined acceptable risk, cost-benefit analysis, and technology feasibility. According to Selck et al., (2016), "The fact that risks and benefits are dynamic, and thus will change, means that past experiences will increasingly no longer be a reliable guide to the future, particularly given climate change" (p.9).

While there are many examples of traditional models of risk assessments protecting human health, traditional models have also been found to lack parameters specific to engineered nanomaterials. Because of the differences among the categories of nanoparticles, each material has to be assessed individually and may require tailor-made regulations. Therefore, traditional methods simply are not applicable (Sylvester, Abbott, & Marchant, 2009). The dilemma is best summarized by Dr. Kristen Kulinowski in a blog written by Robert Feris (2014) from Emerson Inc., "We [scientists and regulators] are in this awkward middle territory where we have just enough information to think there is an issue, but not enough information to really inform policymakers about what to do about [policy] " (¶ 4).

The aforementioned comment addresses the need for government regulators and policymakers to be more cognizant of industries' efforts to produce and apply nanomaterials in commercial and consumer products. In addition, industrialists need to develop preventative measures to protect humans and the environment from exposure to nanomaterials (Charitidis, Trompera, Vlachoui, & Markakis, 2016).

Efforts made in regulatory and administrative controls in the risk management process of nanomaterials must be taught in professional training and formal education. The following sections outline how the course was designed which allowed for continual updates over time as advancements in nanomaterials and nanotechnology processes evolve and require new risk management methods.

Development of Course

The course was developed through a 2012 National Science Foundation program grant mechanism entitled Nanotechnology Undergraduate Education (NUE), NSF DUE #1242087. Modules were created to insert content from engineering, engineering technology, and industrial technology fields of study. Subsequently, the content exploited in the modules were then used to develop the 4000-level course. Table 1 lists the modules used to develop the course.

Table 1.
Modules Developed with Topics and Subtopics. The table includes a list of NSF funded modules that were integrated into engineering, engineering technology, and technology courses.

Module #	Topic and Subtopics	Subject Matter Experts Involved
1	Overview of Occupational Health & Safety: Methods and practices, Theories of accident causation, Accident investigation & reporting, Hazards control & communication. Introduction to nanotechnology: Nanotechnology ASTM E2456 standard terminology, Introduction to nanomaterials, Overview of manufacturing processes.	3
2	Applications of Nanotechnology, Environmental: Nanomaterials for groundwater remediation, Nanoparticle use in pollution control. Applications of Nanotechnology, Health: Drug deliver, Gene delivery, Nanoparticles (liposomes and dendrimers), Imaging, Molecular diagnostics, Cardiac therapy, Dental care, Orthopedics applications. Applications of Nanotechnology, Energy: Solar and fuel cells, Internal combustion engines. Applications of Nanotechnology, Information and Communication: Memory storage, Novel semiconductor device, Novel optoelectronic device, Displays. Applications of Nanotechnology, Heavy Industry: Aerospace, Construction materials, Automotive. Applications of Nanotechnology, Consumer: Cosmetic, Textile, Optic, Agriculture, Sports.	4
3	Assessing Nanotechnology Health Risks: Dose-response assessment, Dose-response evaluation, Risk characterization. Human health and toxicology: Short and long-term toxicity studies, Understanding and determining toxic doses. Role of the National Institute for Occupational Safety and Health (NIOSH). Nanotechnology safety programs in the workplace: Training and incentives.	3
4	Sustainable nanotechnology development. Developing environmental regulations pertaining to nanotechnology. Analyses of nanoparticles in environment. Nanotechnology and our energy challenge. Life cycle risk assessment (LCRA) for sustainable nanotechnology applications.	3
5	Environmental risks assessment. Nanoparticle transport, aggregation, and deposition. Treatment of nanoparticles in wastewater. Potential ecological hazard of nanomaterials. Environmental toxicology and risk assessment. Balancing risks and rewards.	3

6	Ethical and Legal Aspects of nanotechnology. Ethical principles: Case scenarios in private industry and government. Legal duties and regulations: Manager's responsibility and worker's compensation. Role of the Occupational Safety and Health Administration (OSHA), NIOSH, and Environmental Protection Agency (EPA).	3
7	Developing a Risk Management Program. ASTM and OSHA guidelines for working with nanomaterials. Prevention and Control Strategies: Engineering Controls, Administrative Controls, Personal protective equipment. Nanotechnology risk management in Total Safety Management (TSM) and Quality Management (QM) frameworks.	3
8	Presentations of case studies or research project. Industry Safety: Representative from different companies. University Safety Officers: University representatives from EHS.	NA 2 2

The 4000-level course derived from the eight modules listed in Table 1 is entitled *Principles of Risk Management for Nanoscale Materials* and its purpose is to address and explain health and environmental risks of nanotechnology to undergraduate students. Upon completion of the course, students would be able to:

- Describe the health and environmental risks of nanotechnology,
- Understand how to work in a group and conduct systematic research to write a group-based term paper on case studies and/or research topic, and
- Explain approaches to assessing life-cycle risk assessment of nanotechnology products and processes.

Quality Assurance of Course

The quality of the course was measured by its module content and was verified by the program's Nanotechnology Advisory Council (NAC). The NAC was a team of 6 forward-thinking experts from academia and industry with expertise in manufacturing, environmental health, occupational health, industrial hygiene, and advanced materials. The NAC assisted in providing feedback, improving the quality, and identifying gaps in the content. Two meetings were held; one was scheduled in the Spring 2013 semester (January 2013) and was designed to finalize contents of the introductory and advanced courses. The second meeting was held at the end of Spring 2014 semester (June 2014) to discuss results of the advanced course and the overall success of the project. In addition to these face-to-face meetings, project investigators communicated with NAC members via teleconferencing, video conferencing, and emails during the project period.

Assessment of Assignments

Students enrolled in the modules and courses were subjected to quizzes, critical-thinking essays, internet assignments, and an end-of-semester project on developing a risk management plan for nanomaterials in the workplace. Students had the opportunity to express their creativeness on assignments that related to what they perceive (i.e. example scenarios where workers participated in an action and students assessed the action as the perceived "right way" versus the "wrong way"). Students identified ethical issues and the consequences of not properly following protocols for cleaning countertops with deposited carbon nanotubes in the workplace. In this case, the students were assessed on the underlying ethical message of "clean your workspace" or "do nothing". Management training included identifying the consequences of "do nothing" and teaching "not repeat the same mistake". Table 2 provides the assessment methods used for students' assignments. Table 3 illustrates the grading rubric used for the assignments.

Table 2.
Assessment Criteria of Methods for the Principles of Risk Management for Nanoscale Materials

Method of Assessment	Method of Grading	Frequency of Assessment
Exams, Quizzes based on videos/guest speakers	Percentages, Grading rubric	Weekly, Bi-Monthly Mid-Term Semester
Group-based paper on case studies	Percentages, Grading rubric	Weekly, Bi-Monthly, Mid-Term Semester
Semester projects	Percentages, Grading rubric	End of the semester

Table 3.
Grading Rubric for assignments-Content Knowledge

Poor- below 65%	Marginal 65-79%	Competent 80-89%	Exemplary 90-100%
Knowledge of topic is unacceptable. Fails to meet goals and objectives for the topic. • Shows no insight or critical thinking • Poor communication • Lack of understanding of material and how it relates to other disciplines	Demonstrates minimal knowledge of the topic. Met some goals and objectives for the topic. • Shows little insight or critical thinking • Shows some understanding of the readings; synthesis of concepts is unclear • Provides vague literature examples, not tied to the topic	Demonstrates acceptable knowledge of the topic. Met the goals and objectives for the topic. • Shows some insight and critical thinking • Shows understanding of readings and synthesizes concepts • Provides literature and examples to support topic	Demonstrates in-depth knowledge of the topic. Beyond the goals and objectives for the topic: • Exceptionally creative/critical thinking • Understanding of reading; synthesizes concepts • Provides numerous supportive references/ examples

Towards the end of the semester, the twenty-one students enrolled in the course were required to draft a research paper to demonstrate their applied understanding of course material and learning objectives. The term paper challenged the students' learning about Occupational Health. They were asked to select one of three term paper topics (Workplace, Administrative Controls, and Regulation & PPE). The instructions were to write the paper based on eight of the module topics (overview & introduction, applications, health risks, sustainability, environmental risks, ethics and legality, risk management, and case studies) or any combination thereof. Table 4 shows the rubric of each term paper versus the module topic included. The number located within each cell corresponds to the term paper topic discussed (i.e. 1 = Workplace; 2 = Administrative Controls; and 3 = Regulation & Personal Protective Equipment (PPE)).

Table 4.
Selection of Students' Term Paper Choice and Integration of Module Topics.

TERM PAPER NUMBER \ MODULE TOPIC NUMBER	1	2	3	4	5	6	7	8
1	1						1	
2	2	2		2				
3				3	3	3		
4	3	3				3		3
5		2	2	2				
6				1	1	1		
7			3				3	
8	2	2	2	2				
9	3					3		
10	2					2		
11	2	2	2					
12		3						
13	2	2	2				3	
14		3	3	3	3	3		3
15					2			
16	2	2	2		2			
17		3	3					
18		2				2	2	
19								
20			1	1		1		1
21	1			1	1	1	1	

Note: The three term paper topics include 1=Workplace, 2=Administrative Controls, 3=Regulation & PPE. The number for term paper topic is populated within each cell and are aligned against the module topic number, which includes 1=Overview & Introduction, 2=Applications, 3=Health Risks, 4=Sustainability, 5=Environmental Risks, 6=Ethics & Legality, 7=Risk Management, 8=Case Studies. Empty cells mean that the term paper did not include any content from the corresponding module.

All but one student participated in the term paper assignment. Of the students who turned in a term paper, 20% chose to write about the Workplace, 45% wrote about Administrative Controls, and 35% wrote about Regulation and Personal Protective Equipment. None of the students included all of the module topic numbers. The average number of module topics included was 3, where module 2 (applications) was the most commonly cited topic (55% of students included a discussion about applications in their term paper). The least commonly cited module was number 8 (case studies). Clearly, the students more likely discussed specific examples of nanotechnology applications as opposed to discussing examples of occupational health case studies. One student was able to incorporate 6 uniquely identifiable module topics within the term paper draft, where one student was only able to incorporate one topic. The remaining students incorporated 2, 3, 4, or 5 topics (6 papers included 2 module topics; 7 included 3; 4 included 4; and 1paper included 5 module topics).

Students' Assessment of Course Content

RESEARCH DESIGN

Survey research (descriptive) design was used to obtain the participants' perspectives by answering five research questions. According to Isaac and Michael (1997), this research method is used, "to describe systematically a situation or area of interest factually and accurately" (p.46).

This design generates means and frequencies to obtain the students' perspectives of the course. To ascertain the students' perspective for the course, five research questions were used:

1. How easy was the course to understand?
2. Were the topics covered in sufficient detail?
3. Did the course provide real work experience?
4. What was the students' perception of the quality of course materials?
5. What was the students' overall perception of the course?

STATISTICAL ANALYSES

Descriptive statistical analysis was used on the obtained data to summarize data set which is governed by research questions. The Crosstab function in Statistical Package for the Social Sciences (SPSS) Version 20 generated the results. The rationale for the descriptive analysis was to collect the frequency of the participants' perception based on the 5-Point Likert scale.

SURVEY USED TO ASSESS STUDENTS' PERSPECTIVE

The survey consists of five questions with a 5-Point Likert scale (poor, fair, neutral, good, and excellent). The questions were designed to obtain specific data from respondents in an effort to minimize confusion of the participants and investigators alike. A qualitative (i.e. written comments) response section was included to get insight on the students' perspectives. Blackboard Learning Management System (Blackboard Inc., Washington, D.C.) was used to store the end-of-the semester surveys. The course was taught in the Spring semester of 2014.

PARTICIPANTS

There was a total of twenty-one (21) students enrolled for the spring course. The 21 students were composed of 4th and 5th year college students who self-identified as "seniors". For each research question, all twenty-one students responded to the survey. Eleven of the students were female and 10 were male.

Results of Students' Assessment

The first research question was: How easy was the course to understand? Table 5 shows the students' responses. 52% of the students rated this question "excellent", while 38% rated it "good". 9% of the students rated the question either "fair" or "neutral". None of the students rating this question as "poor". In summary, the students generally felt that the course content was easy to understand.

Table 5.
How easy was the course to understand?

	LIKERT SCALE				
	Poor	Fair	Neutral	Good	Excellent
TECH 4313 (SPRING 2014)	0	1	1	8	11

The second research question was: Were the topics covered in sufficient detail? Tables 6 shows the students' responses. As with question 1, 52% of the students rated this question "excellent", while 38% rated it "good". 9% of the students rated the question as "neutral". None of the students rating this question as "poor" or "fair". In summary, the students agreed that the content discussed within the course was delivered in sufficient detail.

Table 6.
Were the topics covered in sufficient detail?

	LIKERT SCALE				
	Poor	Fair	Neutral	Good	Excellent
TECH 4313 (SPRING 2014)	0	0	2	8	11

The third research question was: Did the course provide real work experience? Table 7 shows the students' responses. For this question, 57% of the students rated this question "excellent", while 33% rated it "good". 9% of the students rated the question as "neutral". None of the students rating this question as "poor" or "fair". Out of the 21 students, 19 responded "good" to "excellent" to the course containing real work experience.

Table 7.
Did the course provide real work experience?

	LIKERT SCALE				
	Poor	Fair	Neutral	Good	Excellent
TECH 4313 (SPRING 2014)	0	0	2	7	12

The fourth research question was: What was your perception of the quality of course materials? Table 8 shows the students' perceptions. 47% of the students rated this question "excellent". Another 47% rated it "good". 4% of the students rated the question as "neutral". None of the students rating this question as "poor" or "fair". The majority of the students agreed that the quality of course materials was "good" to "excellent".

Table 8.
What was the students' perception of the quality of course materials?

	LIKERT SCALE				
	Poor	Fair	Neutral	Good	Excellent
TECH 4313 (SPRING 2014)	0	0	1	10	10

The fifth research question was: What was your overall perception of the course? Table 9 shows the students' responses. 57% of the students rated this question "excellent"; while 38% rated it "good". 4% of the students rated the question as "neutral". None of the students rated this question as "poor" or "fair". Majority of the students' perception of the course ranged from "good" to "excellent" in terms of a quality learning experience for content in the risk management of nanomaterials.

Table 9.
What was the students' overall perception of the course?

	LIKERT SCALE				
	Poor	Fair	Neutral	Good	Excellent
TECH 4313 (SPRING 2014)	0	0	1	8	12

Qualitative Response Section

The qualitative response section of the survey included an opportunity for participants to write (in their own words) their perspectives of the course and its contents. It was also the opportunity for the students to provide input as to the strengths and weaknesses of the course. There were seven responses among the twenty-one students.

Five comments centered around course strengths:

- "[I] learned about real world applications"
- "I feel I have an advantage over other students in regards to nanotechnology"
- "Helpful instructor with prompt feedback"
- "Learning how nanomaterials can be harmful"
- "Easy to understand slides and examples"

Two comments centered around course weaknesses:

- "One weakness was not knowing some of the nanomaterials and understanding how they work"
- "A list and guide of nanomaterials can be helpful"

All responses were constructive and were taken seriously to make continuous improvements for the course.

Conclusion and Discussion

The data presented in this paper is not intended for generalization of students' perceptions of all nanomaterial risk management courses; however, we believe the data is representative of course content and student responses for a new technology health & safety class in STEM. According to the data, students had a refreshing experience and appreciated the new technology (i.e. nanotechnology). From the students' class discussions and term papers, it was clear that the course content allowed students to perceive the relative safety or danger associated with nanomaterials. The term papers written by students, provided some in-depth experiences about the importance of planning for preventative hazards.

As nanomaterials become more abundant in industry and, risk management practices involving standard material measurements, engineering controls, personal protective equipment, and workplace training will constantly change. To keep up with advances of nanomaterials, professionals must maintain professional development education credit to ensure their ability to prevent and respond to worker hazards.

This research project is an example of one of the first steps universities took when introducing nanotechnology health and safety courses for undergraduates. The course can be easily adapted for graduate students as well as for professionals currently working in industry. The students who participated in this course and its assessment provided valuable input for improvements as well as the development of subsequent content.

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