Nanotechnology Safety Training: Addressing the Missing Piece

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Abstract

This OSHA Susan Harwood Grant addressed nanotechnology safety training for workers and was critical for building a path for future training/education courses. The purposes of the grant were to facilitate training and to assess the outcomes of the participants' knowledge. Two trainers went to four sites in the United States, including one in Puerto Rico, to conduct eight-hour courses in the Environmental, Health, and Safety (EHS) implications of nanomaterials

A survey was distributed to participants at the end of the course to assess the quality of the course and the instructors. Overwhelmingly, approximately 95% of the participants were satisfied with the quality of the course and instruction.

A pretest was given to the participants to assess if they knew anything about EHS, and a posttest was administered after the training course. A hypothesis test was used to determine the effectiveness of the content of the course. A paired samples t-test was used to ascertain whether there was an improvement in scores from the pretest to the posttest. The findings indicated a statistically significant difference between the group mean scores from the pretest to the posttest. In essence, the participants improved from the pretest to the posttest scores as a result of the training. However, there are caution should be taken when addressing the results as the sole indicator of the participants' success.

Introduction

The purpose of this article is to illustrate the findings/assessment of the program funded by an OSHA Susan Harwood Grant. Although huge amounts of data were collected for this article, the authors displayed only data that directly addressed the research questions.

Nanotechnology is emerging as the next frontier of cutting-edge science and engineering. Nanotechnology has provided researchers and industry with a new avenue to develop products that may revolutionize the world as we view it. The National Nanotechnology Initiative has estimated that by 2015, the economic global impact of nanotechnology could reach around $1 trillion (Wedin, 2006). Industry has the monumental challenge of preparing a workforce to think and develop below the 100-nanometer (nm) level. Working with materials on the nanoscale requires specialized training and a technical background that is needed to manufacture engineered nanomaterials (ENMs) (Trybula, Fazarro, & Kornegay, 2009). Researchers, technicians, manufacturing engineers, and production workers will be needed for a nanotechnology workforce (NNI, 2009). Dr. Mihail Roco, NSF Senior Advisor on Nanotechnology, is one of the leaders promoting nanotechnology workforce education/training. By 2015, there will be approximately two million workers globally in nanotechnology (Roco, 2003). Roco stressed the training of people is vital for long-term success in the field of nanotechnology (Roco, 2001).

Workers are producing carbon nanotubes in various applications (e.g., conductive plastics and aeronautical uses) (Nanocyl, 2009). The workforce in these types of companies, such as SouthWest NanoTechnologies, Bayer, and Nanocomp Technologies, which produce ENMs is estimated to contain at least 620 workers. The estimated growth for this product is at an annual pace of 15-17%, and this represents only one of many different classes of nanomaterials (Nanoparticle Task Force ACOEM, 2011). A report identified 61 U.S.-based companies that manufacture or handle carbon-based nanomaterials, in particular carbon nanotubes (Nanoparticle Task Force ACOEM, 2011). This report is disturbing because 61 companies may have inadequate safety procedures for workers who handle EMNs, and most important, workers may not have the proper training to identify potential hazards, which may be very dangerous to welfare of workers and others outside the confines of the workplace. According to studies, some carbon nanotubes—the most researched and produced in the industry, from a technological and toxicological viewpoint—have produced asbestos-like symptoms in rodents (Takagi, Hirose, & Nishimura, 2008). Moreover, work is needed to research both the physical and chemical properties of nanomaterials and how these properties relate to unwanted health effects. The properties of nanomaterials cannot be generalized to determine health and safety effects (Fazarro & Trybula, 2011). As new EMNs emerge, there is an increase in the uncertainty of how they will behave (Shatkin et al., 2010). Research about the properties of EMNs will be ongoing; however, there is a need to properly train U.S. nanoworkers in safety.

National and Global Perspective on Nanotechnology Safety

A number of government organizations, such as CDC, NIOSH, NIST, FDA, and ICON, are aggressively establishing a foundation to define fundamentals of nanotechnology safety content. In 2011, the following government organizations were funded to address the research needs to maintain a safe workplace: The U.S. Food and Drug Administration (FDA) requested $15 million; The National Institute for Occupational Safety and Health (NIOSH) requested $16.5 million; and the National Institute for Standards and Technology (NIST) doubled its nanotechnology safety research from $3.6 to $7.3 million (Maynard, 2010). According to Fazarro & Trybula (2011), “This effort to push nanotechnology safety research is novel; however, there is a need for a parallel effort to implement education and training” (para 4). Maintaining workers’ health and avoiding litigation would be a beneficial by-product of avoiding accidents that can result to public mistrust. So, what should be done to prepare this growing workforce to meet the needs of the industry?

U.S. Senators Mark Pryor and Benjamin L. Cardin have introduced the Nanotechnology Safety Act of 2010 (Pryor, 2010) to address future health and safety concerns. According to Mark Pryor:

> Nanotechnology is one of the most important and enabling technologies being developed right now, and it has hundreds of promising applications – from new cancer treatments to improved military machinery to stain-resistant pants," . . . "As these products are developed and used, we must understand any potential risks to human health, safety or the environment. My legislation will help ensure public safety and confidence in the marketplace, and it will support companies that employ nanotechnology materials. (para. 1)

Benjamin Cardin added, "Nanotechnology touches so many facets of our lives today and will play a greater role in the future, but the benefits to industry and consumers come with unknown risks that must be identified and managed appropriately" (Pryor, 2010, para. 3).

A 2011 report entitled *EPA Needs to Manage Nanomaterial Risks More Effectively* provided concerns of industries that produce nanomaterials. The EPA concluded:

> EPA does not currently have sufficient information or processes to effectively manage the human health and environmental risks of nanomaterials. EPA has the statutory authority to regulate nanomaterials, but currently lacks the environmental and human health exposure and toxicological data to do so effectively (U.S. Environmental Protection Agency, 2011, p. 3).

According to this EPA report, there is evidence that agencies that are involved in nanotechnology in the United States are still behind in establishing Environmental, Health, and Safety (EHS) standards.

Regarding the global perspective, the European Commission (2012) is well ahead of the United States in addressing EHS issues of nanotechnology to devise an integrated approach to be safe and responsive toward EMNs. The European Parliament demanded a framework to establish regulations for (1) reviewing and adapting EU laws, (2) monitoring safety issues, and (3) engaging in dialogue with national authorities, stakeholders, and citizens. The European Commission favors the development of nanotechnology; however, safety behavioral, and ethical responsibility should be paramount.

China is behind Europe and the United States on safely handling nanomaterials. China has been focused on the biological and environmental effects of manufactured EMNs (Zhao, Zhao, & Wang, 2008). According to Jarvis and Richmond (2010), some generational gaps (e.g., Baby Boomer, Generation X, & Generation Y) exist among researchers on how to approach EHS difficulties of nanomaterials. This can be a serious problem in the future in terms of worker safety and perhaps increased illnesses and deaths in the workplace.

The National Nanotechnology Initiative (NNI) (2010) conducted a study on Chinese nanotechnology. The NNI concluded that scientific gaps are evident, which include little data to support workers' exposure to nanoparticles/nanomaterials at the worksite. Also, workers who have been examined had been exposed for long as 13 months. China has not created sufficient and suitable industrial hygiene practices to protect workers; to exacerbate the problem peasants were employed at the worksite that did not have any formal training in industrial hygiene or knowledge of the toxicity effects of the nanoparticles/nanomaterials at the worksite.

The Next Step

Unlike general safety training programs, such as HAZWOPER (safety training for the micron world), the nano world is very different, and content must be designed so that workers can understand the environmental, health, and safety hazards of manufactured materials below the 100nm realm. In the semiconductor industry, workers design products in the micro realm. In this area, safety practices have been established for over 30 years. Safety awareness at the nanolevel is mind-boggling, and it is complicated to imagine workers developing materials that are far beyond the naked eye. Opening up a new arena in which industry, researchers, and government agencies have barely scratched the surface dealing with the EHS issues, will be a monumental challenge.

The lead university (Rice University), Texas State University, and the University of Texas at Tyler collaborated to receive funding for the country's first OSHA grant addressing the training needs of safely handling nanomaterials in the workplace. The grant addressed the critical and urgent need for rigorous, science-based, and comprehensive training materials to directly address the safe handling of nanomaterials. There are best practices (CDC, 2012; OSHA, 2012; Good Nano Guide, 2011) for safely handling nanomaterials published on websites. However, no empirical studies have addressed perceptions and effectiveness of training workers on nanotechnology safety.

Training Content Development

The development of the training package is derived from the brightest minds in nanotechnology safety as represented by organizations such as the Center for Biological and Environmental Nanotechnology (CBEN)—Rice University, The Lippy Group, Texas State University, The University of Texas—Health and Science Center at Houston, and the International Chemical Workers Union. Internal and external advisory boards were formed to ensure the topics were taught and input was provided for program improvement.

The training program consisted of establishing an eight-hour course to cover ENM occupational health and safety issues to emphasize human exposure. Seven topics were used to develop the modules. See Figure 1 for illustration. Two trainers went to four locations, including Puerto Rico, to conduct the training. A research study was conducted to ascertain both if learning outcomes were achieved and participants' perspectives on the program.

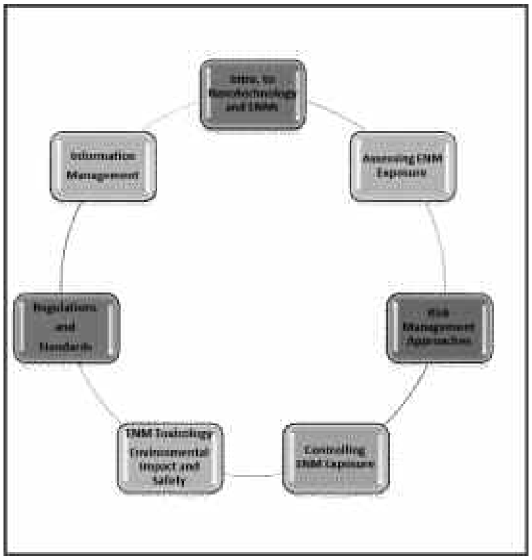

Figure 1. Seven modules used for training program funded by OSHA-Susan Harwood

Purpose of Study

The purpose of this study was twofold: (1) determine if the participants successfully completed the seven topics and (2) determine the participants' perspectives of the program. To ascertain the success of the program, research questions and hypothesis statements were developed.

Research Questions

1. What were the participants' *Cohort 2011* perceptions on the Nanotechnology Safety Training?

2. Was there a difference between the participants' *Cohort 2011* mean scores on the pretest and posttest?

The hypotheses statements that follow are at a .05 alpha level for research question 1. The alpha level of .05 is commonly used in education because of the likelihood of making Type I and Type II errors.

Hypothesis Statement

1. Ho: There is no difference between the participants' mean scores on the pretest and posttest.

   Ha: There is a difference between the participants' mean scores on the pretest and posttest.

Methodology

Research Design

The research design for hypothesis statement 1 employs a minimal control, one-group, pretest-posttest design (Campbell & Stanley, 1966). Even though there can be a significant result from the design, there are disadvantages. For example, there is no assurance that the treatment (training material) will be the only major factor in participants' learning.

Research question two uses a survey research (descriptive) design to obtain the participants' perspectives. 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).

Statistical Analyses Used

The study utilized descriptive analysis and a paired samples t-test. The rationale for the descriptive analysis was to collect the frequency of the participants' perception based on the 4-point Likert scale. The paired samples t-test was used to determine if there was an increase in the group-mean scores from the pretest to posttest.

Population of Participants

The nanotechnology safety training targeted small- to medium-sized ENM fabrication plants, processing companies, and research facilities. There are many small- to medium-sized companies that have no (or few) dedicated safety professionals on staff; instead, in such companies an engineer or a scientist (if anyone at all) may be tasked with health and safety duties as an adjunct to that staff member's primary responsibilities. A worker who fulfills such a dual role must find and apply reliable information about the safe handling of ENMs so that he or can disseminate critical information within a facility. Even when a trained safety professional is on staff, the worker will likely have had little prior experience specifically with ENMs and would benefit from learning how to apply his or her existing professional knowledge to this new class of materials.

Flyers were used for each site to invite workers to receive training. Tables 1a and 1b illustrate the training sites and number of attendees for 2011.

Table 1a: Training Locations

Training Location	City-State/Territory
Mission College	Santa Clara, CA
Univ. of Cincinnati	Cincinnati, OH
Labor College	Silver Spring, MD
University of Puerto Rico	Puerto Rico

Table 1b: Number of Participants by Training Location

Training Location	No. of Attendees #
Mission College	11
Univ. of Cincinnati	37
Labor College	25
University of Puerto Rico	30

n = 103

There was a wide range of participants, differentiated by job title and level of education, who attended the training sessions for 2011. See Tables 2a and 2b.

Table 2a: Number of Participants by Job Title

Job Title	No. of Attendees*
Environmental Health	3
Injury and Prevention Control	1
Occupational Safety	25
Occupational Health Nursing	1
Occupational Medicine	4
Industrial Hygiene	23
Other	

* Note: The number of attendees from the Table 2a does not reflect the number of attendees in Table 1b. There were some people who dropped out or left early.

Instruments for Study

The instruments for the study were a pretest, posttest, and end-of-the-course survey. The pretest consisted of 14 questions (5 true/false), and 9 short-answer questions). The

Table 2b: Number of Participants by Level of Education

Education Level	No. of Attendees*
High School	5
Some College	13
Associate Degree	2
Bachelor of Arts or Science	30
MS/MA/MPH	7
Doctorate	44

* Note: The number of attendees from the Table 2a does not reflect the number of attendees in Table 1b. There were some people who dropped out or left early.

posttest contained the same number of questions; however, the questions were reworded and ordered differently. The end-of-the-course survey contained three sections (demographic, rate the instructors, and course experience), for a total of 15 questions. There were14 statements with a 4-point Likert-type scale (Excellent, Good, Fair, and Poor). Cronbach's alpha was performed by Statistical Package for the Social Sciences (SPSS) to test for reliability of the survey instrument. There was a reliability of .721, which is considered acceptable. Face validity was conducted by the internal and external advisory panel to assess whether or not the questions were appropriate to evaluate the participants in the training program.

To prevent internal threat to validity, the posttest questions were rearranged and reworded slightly from the pretest. The instruments were developed to address assessment needs for reporting to OSHA.

Data Collection Procedures

The data from the pretests, posttests, and end-of-the-course evaluations were collected at the end of the training sessions for each site. Data were collected and stored on Excel spreadsheets. Steps were taken to ensure the pretests and posttests score were matched by participant. The data were imported to SPSS to generate results.

Results

Survey Results

The results are displayed in this section for the research questions. The SPSS-Crosstab function was used to generate frequencies by the 4-point Likert-type scale for each statement that was answered by the participants. The research question stated, *What were the participants' (Cohort 2011) perceptions of the Nanotechnology Safety Training?* Tables 3-5 addressed the quality of the course by each training site. Participants at the training sites—Santa Clara, University of Cincinnati, Labor College, and University of Puerto Rico believed that the content suited their requirements. See Table 3.

Participants at the training sites (Santa Clara, Univ. of Cincinnati, Labor College, and Univ. of Puerto Rico) responded good to excellent that the topics were covered in detail. See table 4.

Table 5 illustrates the majority of the participants at each training site rated the nanotechnology safety course was good to excellent.

Table 3. Was the content suited to your requirements?

n = 103

	Likert-Type Scale				
Training Site	**Fair**	**Good**	**Excellent**	**Not Answered**	**Total**
Santa Clara	1	5	4	1	11
University of Cincinnati	3	18	16	0	37
Labor College	4	17	4	0	25
Univ. of Puerto Rico	4	12	14	0	30

Table 4. Were the topics covered in sufficient detail?

n = 103

	Likert-Type Scale				
Training Site	**Fair**	**Good**	**Excellent**	**Not Answered**	**Total**
Santa Clara	0	8	3	0	11
University of Cincinnati	5	16	15	1	37
Labor College	0	13	12	0	25
Univ. of Puerto Rico	3	14	13	0	30

Table 5. Overall rating of the course follows:

n = 103

Likert-Type Scale					
Training Site	**Fair**	**Good**	**Excellent**	**Not Answered**	**Total**
Santa Clara	0	6	5	0	11
University of Cincinnati	1	16	20	0	37
Labor College	1	10	12	2	25
Univ. of Puerto Rico	1	13	16	0	30

Table 6. Instructors have the ability to provide real world experience.

n = 103

Likert-Type Scale				
Training Site	**Fair**	**Good**	**Excellent**	**Total**
Santa Clara	0	5	6	11
University of Cincinnati	5	15	17	37
Labor College	2	3	20	25
Univ. of Puerto Rico	1	10	19	30

Table 7. Instructors have knowledge of the subject matter.

n = 103

Likert-Type Scale			
Training Site	**Good**	**Excellent**	**Total**
Santa Clara	2	9	11
University of Cincinnati	7	30	37
Labor College	2	23	25
Univ. of Puerto Rico	7	23	30

Table 8. Instructors' presentation abilities were . . .

n = 103

Likert-Type Scale					
Training Site	**Fair**	**Good**	**Excellent**	**Not Answered**	**Total**
Santa Clara	0	1	9	1	11
University of Cincinnati	1	14	22	0	37
Labor College	0	8	17	0	25
Univ. of Puerto Rico	1	4	25	0	30

Table 9. Overall rating of the instructors . . .

n = 103

Likert-Type Scale				
Training Site	**Fair**	**Good**	**Excellent**	**Total**
Santa Clara	0	1	10	11
University of Cincinnati	1	7	29	37
Labor College	2	4	21	25
Univ. of Puerto Rico	1	5	25	30

Table 10. Materials, handouts, and activities useful . . .

n = 103

Likert-Type Scale				
Training Site	**Fair**	**Good**	**Excellent**	**Total**
Santa Clara	0	7	4	11
University of Cincinnati	4	13	20	37
Labor College	1	12	12	25
Univ. of Puerto Rico	1	13	16	30

The next tables address the quality of the instructors and materials by each training site. See Tables 6 through 11. In all training sites for Table 6, participants believed the instructors did a good to excellent job providing real-world experience for safely handling nanoscaled materials. The majority participants in the training program indicated the instructors provided real-world experience to the course. See table 6.

The participants at the training sites rated the instructors' knowledge of nanotechnology safety from good to excellent. See table 7.

In Table 8, participants who completed the survey rated the instructors' abilities to present the material as good to excellent. See Table 8.

The majority of participants at the training sites rated the instructors as excellent for delivering the training materials. See Table 9.

The participants perceived the materials, handouts, and activities were useful for the training course. See Table 10.

In Table 11, all participants from the training sites rated the quality of the overall materials from good to excellent.

Tables 12-14 illustrate the importance of having nanosafety certification at the worksite.

All participants who answered the survey question agreed that they would consider being certified.

About 50% of the participants at the training sites would consider being certified in nanotechnology safety. See Table 12.

Three out of four training sites agreed that certification would be valuable to the participant and to the employer. University of Cincinnati was split on whether nanotechnology safety certification would be valuable to the company as well as for the individual. See Table 13.

All four of the training sites agreed or strongly agreed that certification in nanosafety is important to the field. Ten participants from

Table 11. Overall quality of the training materials

n = 103

	Likert-Type Scale				
Training Site	**Fair**	**Good**	**Excellent**	**Not Answered**	**Total**
Santa Clara	0	6	5	0	11
University of Cincinnati	0	16	19	2	37
Labor College	0	13	12	0	25
Univ. of Puerto Rico	1	8	20	1	30

Table 12. After this training, would you consider becoming certified in nanosafety?

n = 97*

	Decision Type			
Training Site	**Yes**	**No**	**Do not know**	**Total**
Santa Clara	9	0	1	10
University of Cincinnati	20	15	1	36
Labor College	10	11	0	21
Univ. of Puerto Rico	26	4	0	30

*Note: Six participants did not answer.

Table 13. Would certification in nanotechnology safety be valuable to you and your employer?

n = 96*

	Decision Type			
Training Site	**Yes**	**No**	**Do not know**	**Total**
Santa Clara	10	0	0	10
University of Cincinnati	18	15	3	36
Labor College	17	8	0	25
Univ. of Puerto Rico	25	0	0	25

*Note: Seven participants did not answer.

Table 14. Certification in nanotechnology safety is important to the field.
n = 96*

	Likert-Type Scale					
Training Site	**strongly disagree**	**disagree**	**neutral**	**agree**	**strongly agree**	**Total**
Santa Clara	0	0	1	7	2	10
University of Cincinnati	1	2	8	16	8	35
Labor College	0	0	0	11	10	21
Univ. of Puerto Rico	0	0	0	30	0	30

*Note: Seven participants did not answer.

Labor College agreed strongly that to obtain certification is important. See Table 14.

To determine effectiveness of the course training, a paired-samples t-test was used. The paired-samples t-test requires a sample size of 30+ (Pallant, 2005), which was adequate for answering the hypothesis statement. The material taught at each training site was identical and grouped as Cohort 2011 to achieve the necessary sample size. Ninety-eight participants completed the pretest and posttest. Determining significance for each training site was not possible because of the unequal sizes of the enrollment. To verify the SPSS output was valid, assumptions were checked to determine if there were any violations. There were no violations in the assumptions.

The paired-samples t-test was conducted to determine the course effectiveness—if there was an increase of the mean group score of the participants from the pretest to posttest based on the training material taught. There was a statistically significant increase in the posttest scores from the pretest ($M = 7.939$, $SD = 5.9327$) to the posttest [$M = 15.571$, $SD = 4.7883$, $t(98) = -13.482$, $p < .0005$]. Therefore, the null hypothesis was rejected and the alternative accepted.

Conclusion and Discussion

The study concluded with positive results for the training program. According to the posttest scores, there was a significant improvement in the participants' knowledge of nano-safety. Even though the participants started at different levels from the pretest, the variation of improvement on the posttest was about even across the training sites. Testing the hypotheses to determine whether there was a significant change in the pretest and posttest group mean score was based on the effectiveness of the training. The study also revealed a statistically significant difference in the pretest and posttest group mean score, which meant that the training material was effective and contributed to the improvement in the posttest scores. The authors suggest that readers approach the findings with caution. The significance of the study is only generalized to the four training sites. One must conclude that there were uncontrollable external variables (i.e., monetary incentives, self-motivation), which may have contributed to the increase of the mean group score of the posttest.

In Tables 13 and 14, the participants believed that nanotechnology safety training is important for the viability of companies who manufacture nanomaterials. Thus, in Table 12, participants agreed that certification would be important to the participants. Agencies like NIOSH, OSHA, and professional organizations—ATMAE, IEEE, ASSE, and others—could pave the way to developing certification. ATMAE has a certification division with four certification exams already developed and in use. As ATMAE expands the organization for new skill sets to continue to meet industries' demands, the organization can be a support mechanism to assist in implementing nanotechnology safety courses. To make this certification a reality, more collaboration is needed among government agencies, industries, and other professional organizations to create a valid and comprehensive nanotechnology safety certification.

The funded grant on training workers in nanotechnology safety is groundbreaking and a catalyst to make educators and government agencies aware of the importance of nanotechnology safety training. As more ENMs are created, industry must become more cognizant of the training needs of the workers. Constant improvement of training materials from research and industry practice will be vital to the field of nanotechnology. A workforce that is well trained in safely handling nanoscale materials will lessen the likelihood of catastrophes and decrease public skepticism. Training materials on nanosafety will become available to the public soon on the OSHA website; however, The Good Nano Guide has similar materials, which are available to the public.

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