120th ASEE Annual Conference & Exposition
FRANKLY, WE DO GIVE A D*MN
June 23-26, 2013

Paper ID #7380

First-Year Engineering Students' Learning of Nanotechnology through an Open-Ended Project

Kelsey Joy Rodgers, Purdue University, West Lafayette

Kelsey Rodgers is currently a graduate student at Purdue University in the School of Engineering Education. She is part of the Network for Computational Nanotechnology (NCN) research team. She conducts research within the First-Year Engineering Program to help understand what and how students are learning about nanotechnology.

Prof. Heidi A. Diefes-Dux, Purdue University, West Lafayette

Heidi A. Diefes-Dux is an Associate Professor in the School of Engineering Education at Purdue University. She received her B.S. and M.S. in Food Science from Cornell University and her Ph.D. in Food Process Engineering from the Department of Agricultural and Biological Engineering at Purdue University. She is a member of Purdue's Teaching Academy. Since 1999, she has been a faculty member within the First-Year Engineering Program at Purdue, the gateway for all first-year students entering the College of Engineering. She has coordinated and taught in a required first-year engineering course that engages students in open-ended problem solving and design. Her research focuses on the development, implementation, and assessment of model-eliciting activities with realistic engineering contexts. She is currently the Director of Teacher Professional Development for the Institute for P-12 Engineering Research and Learning (INSPIRE).

Dr. Krishna Madhavan, Purdue University, West Lafayette

Dr. Krishna P.C. Madhavan is an Assistant Professor in the School of Engineering Education at Purdue University. He is also the Education Director and co-PI of the NSF-funded Network for Computational Nanotechnology (nanoHUB.org). He specializes in the development and deployment of large-scale data and visualization based platforms for enabling learning analytics. His work also focuses on understanding the impact and diffusion of learning innovations. Dr. Madhavan was the Chair of the IEEE/ACM Supercomputing Education Program 2006 and was the curriculum director for the Supercomputing Education Program 2005. In January 2008, he was awarded the NSF CAREER award for work on transforming engineering education through learner-centric, adaptive cyber-tools and cyber-environments. He was one of 49 faculty members selected as the nation's top engineering educators and researchers by the US National Academy of Engineering to the Frontiers in Engineering Education symposium.

Dr. William C. Oakes, Purdue University, West Lafayette

William (Bill) Oakes is the Director of the EPICS Program and one of the founding faculty members of the School of Engineering Education at Purdue University. He has held courtesy appointments in Mechanical, Environmental and Ecological Engineering as well as Curriculum and Instruction in the College of Education. He is a registered professional engineer and on the NSPE board for Professional Engineers in Higher Education. He has been active in ASEE serving in the FYP, CIP and ERM. He is the past chair of the IN/IL section. He is a fellow of the Teaching Academy and listed in the Book of Great Teachers at Purdue University./ He was the first engineering faculty member to receive the national Campus Compact Thomas Ehrlich Faculty Award for Service-Learning. He was a co-recipient of the National Academy of Engineering's Bernard Gordon Prize for Innovation in Engineering and Technology Education and the recipient of the National Society of Professional Engineers' Educational Excellence Award and the ASEE Chester Carlson Award. He is a fellow of the American Society for Engineering Education and the National Society of Professional Engineers.

©American Society for Engineering Education, 2013

First-Year Engineering Students' Learning of Nanotechnology through an Open-Ended Project

Abstract

Nanotechnology is an innovative and highly active field of research and development that presents many opportunities for future graduates. Engineering students should be made more aware of the field of nanotechnology and its potential impact on their academics, careers, and lives. This research team is a part of the NSF-funded Network for Computational Nanotechnology (NCN) and is conducting this research on NCN's initiatives to introduce more students to nanotechnology. Through this study we hope to better understand what first-year engineering (FYE) students learned about nanotechnology through their involvement in a nanotechnology-based design project. Twenty-eight teams' executive summaries were qualitatively analyzed to understand what students discussed in their final descriptions of their design solutions. It was found that teams had difficulty understanding the nanoscale and differentiating it from the micro and atomic scales. It was also found that teams that included specific products and/or applications of nanotechnology in their project solution showed a greater understanding of nanotechnology. Based on these finding, it is recommended that the nanoscale be explained through comparisons to other scales and nanotechnology-based design projects should encourage students to learn about specific products and/or applications of nanotechnology.

I. Introduction

First-year students know very little about nanotechnology.[1-3] The general public is ill-informed about nanotechnogy.[4] This means that high school and college students are not receiving accurate information about a field that is changing many aspects of our world[5-6] and offers many new learning and discovery opportunities.[7-9] A partnership between faculty teaching a required First-Year Engineering (FYE) course at a Midwestern university and one of the university's NSF-funded nanotechnology projects resulted in a FYE design project to address multiple course learning objectives and improve students' awareness and knowledge of nanotechnology. For this project, student teams were to create a simple interactive tool (using MATLAB[10]) to enable high school students to learn about nanotechnology through relevant state-standards for science.

This research team is interested in (1) understanding what the FYE teams learned about nanotechnology through their work on this project and (2) identifying project improvements needed to increase students' awareness and knowledge of nanotechnology. This research is aligned with other work that calls for understanding students' perspectives of nanotechnology to lead to college reform and nanotechnology advancement.[3] Lu (2009) states, "There is a clear need to understand how nanotechnology is perceived and projected on university campuses, identify trends that may hinder the advancement and innovation of nanotechnology, and take remedial actions such as educational reform or public information campaign" (p. 8).[3] The following research questions guide this work: (1) How do students define nanotechnology through their project work? (2) What, if any, examples of nanotechnology do students discuss in their projects? and (3) What science concepts do they relate to nanotechnology?.

II. Literature Review

Although this study is only addressing the factual knowledge that the students gained about nanotechnology in this project, awareness, exposure, and motivation are also important factors that should be considered to help determine the benefits of the current design project.[1-2] Since the study is focused on factual knowledge, this literature review will briefly define some fundamentals of nanotechnology applicable to this study, describe some previous findings to be aware of in teaching nanotechnology, and discuss other nanotechnology educational endeavors.

A. What is Nanotechnology?

Nanotechnology is science, engineering, and technology conducted at 1 to 100 nanometers in size (or on the nanoscale).[3] The two most fundamental concepts that students must understand to begin to study nanotechnology are scale and that there are unexpected [from the macroscale perspective] properties at the nanoscale.[11] The specifics of unexpected property changes at the nanoscale are complex concepts, but there should be a general understanding that there are property changes at the nanoscale. An example of a specific unexpected property change is the coloration of gold. Gold is a shiny gold color at the macroscale, but at nanometers in size gold will appear green and even less nanometers in size gold will appear red.[11] The various scales (i.e. macroscale, microscale, nanoscale, and atomic scale) are defined with their size range and some examples in Table 1.

Table 1. Definitions of Scales[11]

Scale	Definition	Range (m)	Examples
Macroscale	What can be seen by the naked eye	$\geq 10^{-3}$	Human, Ant
Microscale	Too small to see without a light microscope	$10^{-6} - 10^{-4}$	Hair Details, Cell
Nanoscale	Smaller than a cell and bigger than an atom	$10^{-9} - 10^{-7}$	Virus, Width of DNA
Atomic Scale	The size of an atom	$\leq 10^{-10}$	Atom

B. Nanotechnology – Potential Student Learning Difficulties

The scale of nanotechnology is difficult for students to grasp.[11-13] Some authors discuss the importance of understanding the nanoscale, as well as approaches to educate students about this scale in comparison to others.[12-13] Jones, Andre, Superfine, and Taylor (2003) discuss successes in presenting the nanoscale to students through three-dimensional graphics and virtual reality software.[12] Wiebe, Clark, Ferzli, and McBroom (2003) discuss successes of teaching the nanoscale through visual approaches involving sizing charts.[13]

Lu (2009) completed a survey study with undergraduate students to try to better understand their perspectives and knowledge about nanotechnology; this study's findings identified some current students' understandings that may provide insights to future learning difficulties.[3] It was found that when students learned about nanotechnology in the classroom they typically learned about the nanoscale, but they did not connect nanotechnology with its current and potential applications. This was not a problem found for students that learned about nanotechnology through popular science magazines,[3] since the primary focus of articles about nanotechnology are typically on current and futuristic applications. Although an understanding of measurement is foundational knowledge for students, it is an important reminder that there should be a balanced emphasis on applications of nanotechnology. Students with no formal exposure to nanotechnology were also seen to be very accepting of nanotechnology's potential impact on our future without understanding what it is, but they did not seem to be aware of the potential harmful aspects of nanotechnology.[3] Lu (2009) warns that students seem to accept any idea without a critical evaluation because the potentials of nanotechnology seem to be limitless in their minds due to their lack of concrete knowledge on the topic. Due to students' abilities to quickly accept false information, it may be important to continuously monitor students' learning throughout projects and other nanotechnology interventions. Also females were found to be more likely to accept pseudoscience regarding nanotechnology.[3] Despite these predicaments, there are numerous efforts underway to help students learn nanotechnology; some of these are discussed in the proceeding section.

C. **Nanotechnology – Educational Perspective**

Not only are professionals in high demand in the expanding area of nanotechnology,[14] nanotechnology is an area that presents opportunities for students to learn in multidisciplinary[8] and interdisciplinary[9,15-16] environments. Nanotechnology concepts are taught through various approaches, including projects in existing courses with a goal of increased exposure to nanotechnology,[9,12] incorporation in specialized courses regarding pertinent topics,[17] independent research opportunities,[15] instructional units,[13] lectures,[1,15] informative videos,[11] and artistic approaches.[18]

One project approach that has been utilized in first-year engineering (FYE) courses is the implementation of a mathematical modeling project regarding nanotechnology measurements.[9,16] Encouraging first-year science students to get involved in independent research opportunities with faculty mentors, to participate in science learning communities outside the classroom (specifically Nano Club), and to attend an one-hour introduction to nanoscience seminar are three techniques that an eastern state university has found useful in engaging their students through the appealing topic of nanotechnology.[15] At an innovative eastern university, there is a course consisting of primarily computer and electrical engineering students that challenges students to write a research paper about a nanoscale device of their choice.[17] Kim, Kamoua, and Pacelli (2005) indicate that this technique is a starting point and propose further informing students of the differences between micro- and nano- scales through a 3-week module focused on specific devices, computational modeling and design, and a design project.[17] More proactive educational approaches are needed to expose to students to nanotechnology through lectures or hands-on experiences; some believe that this exposure should be implemented in the first-year of engineering or science.[3,15]

III. Research Context

A. Setting and Participants

At a large Midwestern university, all students in the first-year engineering (FYE) Program are required to complete two sequential 2-credit hour courses that focus on learning objectives associated with problem-solving and design, computer tool skills, and teamwork. Of interest to this study, is that both courses facilitate discovery learning through team design projects. The focus of this study is on a specific nanotechnology project that utilized modeling and simulations; it was implemented in four sections of the second semester course in Spring 2012. In Spring 2012, 1651 students were enrolled in 15 sections (up to 120 students per section) of the FYE Program's second semester course. The four sections that completed the nanotechnology project were taught by three instructors. The work of one section was analyzed ensuring that all student teams received the same in-class materials and lectures by one instructor; this ensures that student teams included in the study had the same exposure to nanotechnology in class. The selected section consisted of 28 student teams (with 3 or 4 students per team).

B. Nanotechnology Graphical User Interface (GUI) Project

The project partner for the nanotechnology project was a NSF-funded Network for Computational Nanotechnology (NCN) whose mission is to support the National Nanotechnology Initiative by creating and operating a cyber-platform for expanding and supporting the nanotechnology community formation and growth by sharing computational simulations and educational resources. The platform is called nanoHUB.org. It is an interactive online data and research sharing environment with 64,659 interactive users; the environment primarily consists of online simulations for nanotechnology. The project partner served as the client and set the criteria by which the project solutions could be judged for success. The nanotechnology project required student teams to create an interactive learning module relating nanotechnology to grades 11 or 12 science and mathematics topic as listed in the state standards. To achieve this goal, students were asked to plan and create a fully developed graphical-user interface (GUI) utilizing MATLAB.[10] The students were given access to the project partner's online environment so they could further understand the client for the project (nanoHUB.org). The ultimate project goal was to upload the developed educational tool to nanoHUB's site and make it available for high school students to engage in nanotechnology-related activities. The students were given five clear criteria for success:

1. Clearly show how the rationale for this project will help students learn nanotechnology,
2. Clearly address one state science standard for the targeted grade level,
3. Clearly connect the science or engineering topic to math activities that are appropriate for the targeted grade level,
4. Is highly stimulating and interactive for targeted grade level, and
5. Is easy to use and operate.

This project was to be completed in six milestones. These milestones served to help the teams develop their solution along a predetermined timeline and use design concepts learned in the prerequisite course. The milestones were as follows:

1. Brainstorming (Week 11): This involved brainstorming 30 potential ideas for a solution to the Nanotechnology GUI project and then going through concept reduction using a

decision matrix. The deliverable was a memo to the project partner describing two design ideas the team felt were worth pursuing.

2. Project Storyboard (Week 12): The team selected one idea and used PowerPoint to create a prototype of their solution project partner.
3. Project Layouts and Flowcharts (Week 14): The team fully develop the GUI layout in MATLAB and flowcharted the solution that would need to go behind each layout.
4. Project GUI Beta Version 1 (Week 15): Teams began to convert their flowcharts to MATLAB code. The instructional team provided students with detailed feedback.
5. Project GUI Beta Version 2 (Week 16 – Class A): Teams presented a complete and improved solution to the instructional team. This version was evaluated by the project partner during a class demonstration
6. Project Final Demo and Executive Summary (Week 16 – Class B): Teams gave a final demonstration of their solution to the instructional team and submitted their written documentation. This version was evaluated by the instructional during a class demonstration. Project reports had to demonstrate how the feedback from the clients were incorporated into the final design.

The Nanotechnology GUI project was introduced in Week 11 with a memo from the project partner and a short presentation by the instructional team that highlighted available nanotechnology resources. The final deliverables of the project in Week 16 were the teams' executive summaries and final version of their fully functional GUI solutions. Figure 1 shows a typical opening GUI for the teams' project solutions. The primary content of the GUIs consisted of text, images, and various interactive components (e.g. push buttons, radio buttons, textboxes) to engage the high school user in the teams' nanotechnology-related learning activities.

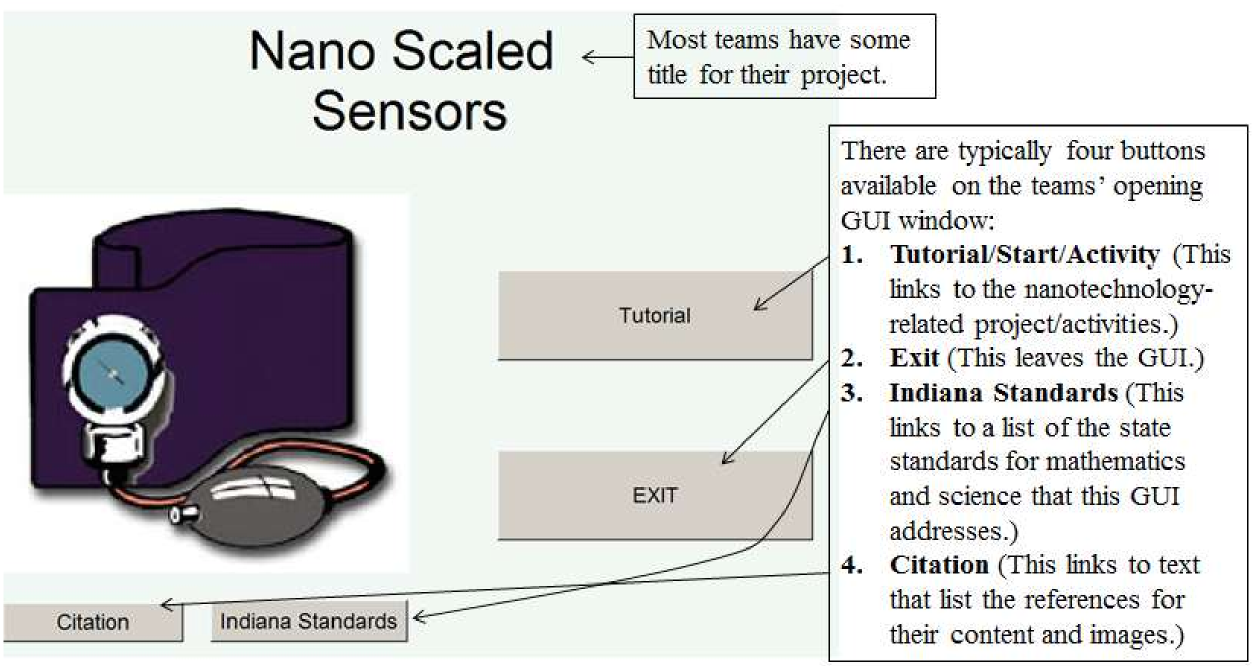

Figure 1: Example of opening GUI window (Team 8)

The primary focus of this study is each team's Project Executive Summary submitted electronically. This assignment asked teams to write a maximum 2-page, single space summary in which they were to address the following questions in a narrative form:

- How is your project specifically related to nanotechnology? Why is your project important for learners?
- How did you incorporate the [network]'s team in your solution?
- What problem are you solving? What is your solution? Briefly describe the grade level target you are targeting, the engineering activity, the science topic, and the math activities. Make explicit reference to the Indiana State Science and Indiana Common Core State Standards for Mathematics addressed by your solution.
- How do you define success? Provide a ***critical*** evaluation of the effectiveness of your program with respect to *each* of the five criteria for a success (see nanoHUB project description). For each criterion, provide ***strengths and weaknesses***.
- So what? Implications? Improvements needed? Next steps.

C. Data and Analysis

The student teams' executive summaries completed in milestone six are analyzed for this initial study in students' learning of nanotechnology through project work. All selected 28 teams' executive summaries were qualitatively analyzed through open coding to elicit themes[19] concerning nanotechnology and any discussed science and math concepts. These themes where then analyzed for patterns. Some of the keywords and discussed concepts were counted to determine the frequency and/or numerically categorize occurrences by number of teams. This concept of quantifying qualitative data to numerically report findings has been used in previous studies, such as Rodgers, Diefes-Dux, and Cardella (2012).[20]

IV. Results

The executive summaries were analyzed for word frequency, how the teams defined or discussed nanotechnology, how teams discussed the size of nanotechnology, the types of technologies that were discussed, and the types of science and mathematics concepts that the teams related with their project.

A. Word Frequency and Presence of Nanotechnology

The executive summaries were analyzed to determine the frequency of references to nanotechnology (Table 2). Teams mentioned nanotechnology as little as 1 time to as many as 13 times with an average of 7 times. (The word counts do not include the team's title pages because team names and titles were not considered part of their actual summary content.) Table 2 also has a general summary of how the teams defined and incorporated nanotechnology shown with an "X" in the applicable columns. Also the last column of Table 2 is marked if the relevant team explicitly stated that their project did not do a good job of meeting Criterion 1 (relating to nanotechnology).

Teams 3, 23, and 26 were the only teams that did not show any attempt to define nanotechnology and did not discuss any technique to incorporate nanotechnology in their projects within their executive summaries. However, all three teams admitted to have a shortcoming of not meeting Criterion1 (teaching nanotechnology) well. Teams 9 and 15 were the only teams that did not discuss any technique of incorporating nanotechnology and did not admit to not successfully meeting Criterion 1; however these teams did attempt to define nanotechnology in their executive summaries. All of the other teams that did not incorporate nanotechnology in some manner admitted to having a shortcoming in meeting Criterion 1. Table 2 also shows that 4 out of the 6 teams that defined nanotechnology by an inaccurate scale (either microscale or atomic scale) incorporated a product into their project. There is no connection seen in Table 2 between the word frequency of nanotechnology and the team's attempt to incorporate or define nanotechnology.

Table 2. Word Frequency and Presence of Components in Teams' Executive Summaries

Team #	Word Frequency of Nanotechnology	Nanotechnology Definition				Nanotechnology Incorporated		Admit Lacking on Nanotechnology (Criterion 1)
		Nano-scale	Other Scale	Field	Application	Product or Application	Text in GUI	
1	6				X	X		
2	11					X		
3	4							X
4	6	X						X
5	7			X			X	
6	9					X		
7	10			X				X
8	6			X		X		
9	9	X		X				
10	5	X			X		X	
11	4						X	
12	7		X					X
13	13	X						X
14	6			X				X
15	6		X					
16	5						X	
17	6			X	X	X		
18	7		X	X		X		
19	5					X		
20	11				X	X		
21	10		X			X		
22	1					X		
23	5							X
24	12		X			X		
25	12					X		
26	9							X
27	2					X		
28	4		X			X		

B. Definition of Nanotechnology

Although every team mentioned nanotechnology at least once (Table 2), almost half of the teams (11 out of 28) did not attempt to define nanotechnology in their executive summaries (Table 3). The teams that did define nanotechnology discussed it using one or more of five different approaches. The five approaches seen were (1) categorizing nanotechnology as a field, topic, or area of research, equating it to the (2) microscale, (3) nanoscale, or (4) atomic scale, and (5) discussing it in terms of a nanotechnology product.

Table 3. Nanotechnology Definitions in Teams' Executive Summaries

Define Nanotechnology	Corresponding Team/s	# of Teams
None	2, 3, 6, 11, 16, 19, 22, 23, 25 – 27	11
Field, Topic, Area of Research	5, 7, 8, 9*, 14, 17*, 18*	7
Microscale	12*, 15, 18*, 24, 28	5
Atomic Scale (e.g. manipulation of individual atoms)	21	1
Nanoscale (e.g. size: nanometers, genetic manipulation)	4, 9*, 10*, 13	4
Discuss a Product or Application of Nanotechnology	1, 10*, 12*, 17*, 20	5

* These teams discussed nanotechnology related to more than one of the categories.

Seven teams discussed or defined nanotechnology as a field, topic, or area of research. Four teams (5, 7, 8, & 14) only referred to nanotechnology in this manner and did not further define it in any way (Table 3). Team 14 wrote, "Nanotechnology is a growing field that can relate to almost any industry." Three teams (9, 17, & 18) further defined nanotechnology by relating it to either a scale or a specific product (Table 3). Team 18 stated, "Structures of molecules in a material affect the strength of said material. Engineering has gone to a new level by designing molecules that have unique strength properties because of microscopic design. This field is known as nanotechnology."

Ten out of 28 teams related nanotechnology to one or more scales. The microscale is the most commonly discussed scale to which teams related nanotechnology. Five teams (12, 15, 18, 24, & 28) described nanotechnology to be on the microscale (Table 3). As stated previously, team 18 described nanotechnology as a field dealing with molecules in "microscopic design". Three teams (15, 24, & 28) only defined nanotechnology as something on the microscale. Team 24 wrote, "…useful on a micro-level, which is the level nanotechnology functions at."

One team (Team 21) defined nanotechnology to be on the atomic scale (Table 3). Team 21 wrote, "First, nanoscience and nanotechnology involve the ability to see and control individual atoms and molecules." The reference to atoms is only on the atomic scale, but the reference to molecules could potentially be on the nanotechnology scale depending on the size of the molecule[21]. Since the team clearly refers to nanotechnology as an ability to control individual atoms, the team's definition of nanotechnology was taken to be related to the atomic scale.

Four teams (4, 9, 10, & 13) defined nanotechnology to be on the nanoscale (Table 3). Two teams (4 & 13) only discuss nanotechnology as related to this scale. Team 4 stated, "… interactions between molecules on the nanoscale, which is very important for work in nanotechnology, as, obviously, all of nanotechnology is on that scale". Since team 4 discusses molecules on the nanoscale, it can be assumed they are only referring to molecules of relevant size since they refer to the nanoscale. Team 16 discusses nanotechnology related to the nanoscale in a more open-ended manner by stating, "Nanotechnology uses particles that are nanometers in size…" Two teams (9 & 10) discuss nanotechnology on the nanoscale, but also define nanotechnology by relating it to other discussed definition categories. Team 9 categorizes nanotechnology as a research topic and discusses size on the nanoscale; they wrote, "…new area of research known as nanotechnology. Nanotechnology is defined as a branch of technology that deals with dimensions and tolerances less than 100 nanometers." Team 9 states the accurate maximum numeric size of the nanoscale and they are the only team that discusses a specific sizing of nanoscale. Although Team 4, 9, & 16 discuss nanotechnology on the nanoscale, none clearly differentiates the atomic scale from the nanoscale. Team 10 is the only team that specifically refers to an example, genes - which are at the nanoscale.

Five teams (1, 10, 12, 17, & 20) discuss nanotechnology by specifically relating it to a product or application of nanotechnology. Two teams (1 & 20) only refer to a specific technology and mention it is an example of nanotechnology. Team 20 states, "Carbon nanotubes are available because of nanotechnology…" The other three teams (10, 12, & 17) discuss some specific product or application of nanotechnology along with some other definition of nanotechnology. Team 10 discusses nanotechnology on the nanoscale and a specific application of nanotechnology; they state, "Nanotechnology is heavily involved in the advances made in modern science and genetics. Genetic engineering involves the direct manipulation of an organism's genome, which is basically the hereditary information. Introducing nanotechnology to this field allows for developments in antibiotics and various other beneficial projects, for example the global food shortages." Team 12 also discusses an application of nanotechnology related to genetic engineering, but refers to this on the microscale. Team 12 wrote, "Nanotechnology is using technology on the molecular or cellular level. The project's connection to nanotechnology is through genetic engineering. The project describes the different methods used to insert genetic material into the cell and the imaging that scientist use to view cells." They never described what genetic engineering is or further defined nanotechnology, but here they expressed that there is some relation between the two.

C. Scales Discussed

Teams did not only state the scale they considered nanotechnology to be within; most teams (19 out of 28) mentioned scales in a more general sense. Teams were only considered to mention a scale if they explicitly stated a scale, level, or size. Four teams (9, 13, 18, & 23) mentioned the macroscale, four teams (7, 18, 24, & 30) mentioned the microscale, fourteen teams mentioned the nanoscale, and one team (28) mentioned the atomic scale (Table 4). The various wording that the teams used to mention the scales are shown under vocabulary used in Table 4.

Table 4. Scales Discussed in Teams' Executive Summaries

Scale	Vocabulary Used	Teams Discussed	# of Teams
Macroscale	"macroscopic", "macroscale", "macrolevel"	9*, 13, 18*, 23*	4
Microscale	"microscopic level", "microscopic", "microlevel"	15, 18*, 24, 28*	4
Nanoscale	"nanoscale", "nanometers", "nanolevel", "nanosized", "nanoscopic"	1–5, 7, 8, 9*, 13, 14, 16, 19, 21, 23*	14
Atomic Scale	"atomic scale"	28*	1

* These teams discussed more than one scale.

The four scales were discussed in a variety of ways, but they were typically not described in great detail. Team 9 was one of the four teams that discussed the macroscale within their executive summary; they wrote, "We believe that our macroscopic analysis of molecules is a great segway into further study in the field of nanotechnology." Team 15 was one of the 4 teams that discussed the microscale; they wrote, "Our project is related to nanotechnology because it deals with how molecules interact with each other on the microscopic level." Team 3 was one of the 14 teams that discussed the nanoscale; they wrote, "All of these things come together to create an engineering activity that allows users to experiment with nanoscopic forces relevant to all engineering disciplines." Team 23 is another team that discussed the nanoscale; they wrote, "The energy principle can be applied at all different levels, including the nano-level. Although the formulas for these different types of energy are not quite the same at the nanoscale as they are at the macroscale, the elementary concepts are still demonstrated in the activity." Team 28 was the only team that explicitly discussed the atomic scale; they also discussed the microscale. Team 28 wrote, "Many chemical reactions take place on an atomic scale, much smaller than the minimum requirement for nanotechnology. … Nanotechnology is dependent on precise calculations on the microscopic level."

D. Nanotechnology Examples Discussed

Almost half of the teams (13 out of 28) discussed some specific device or product related to nanotechnology in their executive summaries (Table 5). Student teams most commonly discussed nanoparticles followed by nanotubes, which is discussed by three teams. Nanowires were mentioned by two teams. Six other technologies were only discussed by one team for each.

Table 5. Technologies discussed in Teams' Executive Summaries

Type of Technology	Teams that Discussed	# of Teams
Nanoparticles	19, 21, 25, 27, 28	5
Carbon Nanotubes	18, 20, 22*	3
Nanowires	8*, 22*	2
Nanosensors	8*	1
Nanofabric	17	1
Nanobots	6	1
Solar Panels	24	1
Quantum Dots	1	1
Circuits (e.g. microchips)	2	1
NONE	3–5, 7, 9–16, 23, 26	14

*These teams discussed two nanotechnology products.

Nanoparticles were discussed in a variety of ways by the five teams. Some discussed the movement of nanoparticles related to some type of movement, chemistry concepts, and protons & neutrons. One specific reference to nanoparticles is shown for each team along with the frequency of times they mentioned nanoparticles in their executive summaries in Table 6.

Table 6. Teams' Discussions of Nanoparticles

Team #	**Quotes on Nanoparticles**	**Frequency:** Nanoparticles Discussed
19	"The implications on nanotechnology are that ***nanoparticles*** can behave like protons and neutrons and so we can sketch their graph."	1
21	"Last, manipulation of ***nanoparticles*** involves a thorough knowledge of chemistry as related to basic and fundamental relationships. …This program allows students to, thus, see and interact with underlying concepts of nanotech by way of the fundamental gas laws, in chemistry."	1
25	"The criteria provided asked that we clearly show rationale for how our project helps students learn about nanotechnology. Each of our chemistry problems relates to a certain type of nanotechnology and gives the student a brief and simple explanation of the ***nanoparticles*** and their use."	2
27	"This interface will allow the user to input data or a function of position and observe various models of the particle's motion relating to its velocity and acceleration. The movement of ***nanoparticles*** is very important to understand because the motion of a particle determines its relative force to other particles and can greatly affect these interactions."	2
28	"Nanotechnology is dependent on precise calculations on the microscopic level. A calculation being off even the slightest bit can radically shift the equilibrium of a reaction when a low amount of molecules is reacting. Furthermore, gold ***nanoparticles*** and other metals have been used as catalysts in reactions."	1

Carbon nanotubes are discussed by three teams (18, 20, & 22).Team 20 & 22 mentioned carbon nanotubes once and Team 18 mentioned carbon nanotubes 15 times in their executive summaries. In the beginning of their executive summary Team 18 wrote, "Our project focuses on ***carbon nanotubes*** and specifically the unique strength of ***carbon nanotubes***. ***Carbon nanotubes*** are available because of nanotechnology, and will become more available with increasing research in the field of ***carbon nanotubes***. We stress ***carbon nanotubes*** because they are an important field of research because ***carbon nanotubes*** have many potential uses as a material because of their unique strength."

Nanowires are discussed by two teams (8 & 22). Team 8 mentioned nanowires twice and Team 22 mentioned nanowires once in their executive summaries. Team 8 related nanowires to the biomedical applications and specifically wrote, "The ***Nano-wires*** from this test are designed to be used in the human bloodstream as a Nano-sized pressure sensors." Team 22 relates magnetic nanowires to LED lighting and specifically wrote, "In our opening slide we describe how and LED is made. The new generation of LED lighting will use electronics constructed from carbon nanotubes and ***magnetic nanowires***. The use of nanotechnology will allow for super thin LED displays, and perhaps usher in a new era of lighting. Our project is important to our users because it introduces them to the physics behind light."

Nanosensors are only discussed by Team 8; they specifically discuss biomedical nanosensors. They wrote, "The final product we created is based on the subject of ***bio-medical Nano-sensors***. The program starts by educating students on conventional methods of measuring blood pressure. The next step is to relate blood pressure measurement on a micro-scale. This shows how micro-sensors can produce more accurate readings and obtain different types of data. The final portion of the program teaches students about how ***bio-medical Nano-sensors*** work and how they are constructed."

Nanofabric is only discussed by Team 17; they discuss the application of nanofabric to sports equipment. They wrote, "Our group's [network name] project relates to nanotechnology in that we relate each of the sports to a developing ***nano-fabric*** that makes equipment stronger and safer."

Nanobots are only discussed by Team 6; they created a program that challenges its users to calculate nanobots' dimensions. They wrote, "For our project, the team created a MATLAB-based program that uses equations determined by nanotechnology engineers to determine the dimensions of different ***nanobots*** used in cellular repair all over the body."

Solar Panels are only discussed by Team 24; they mention solar panels as an example of a nanotechnology based product that is dependent of fractals. Team 24 wrote, "Fractals are intricate, infinite repeating patterns which when applied can be extremely useful on a micro-level, which is the level nanotechnology functions at. Fractals can also be used to maximize area, which is important when constructing systems like ***solar panels***, which involves nanotechnology."

Quantum dots are only discussed by Team 1; they discuss their properties and relate them to light properties. Team 1 wrote, "Our project is related to nanotechnology through a particle called ***quantum dots***. These particles are nanoscale semiconductors that release light photons when energy is added to them. When ***quantum dots*** are produced, their size is controlled to change the amount of energy each dot can absorb. …***Quantum dots*** exemplify the properties of light that are explained in our project. To explain this relationship between nanotechnology and light, an additional interactive portion was added to our project."

Team 2 is the only team that relates their project to circuits, which they felt were related to nanotechnology. They stated, "***Circuits*** are the basis upon which nanotechnology operates, and the principals taught by these exercises, however simple they may be, are directly related to how products such as ***microchips*** and other nano-scaled devices operate."

The teams that did not relate their project to a specific product (e.g. carbon nanotubes) and/or discuss specific things related to nanotechnology (i.e. nanoparticles) more commonly stated that their project did not clearly relate to nanotechnology. Eight teams explicitly stated that they had a shortcoming on this criterion (Criterion 1). All of the teams that stated they had this shortcoming were out of the 14 teams that did not discuss any specific technology or application. The statements made by the 8 teams regarding their shortcoming are shown in Table 7.

Table 7. Nanotechnology Shortcomings Discussed

Team #	Criterion 1 Shortcoming Quotes
3	"Our project clearly meets the criterion of relating to nanotechnology by addressing various forces that are relevant at the nano scale. Because these forces are extremely important for the development or use of literally anything on the nano scale, we believe that this criterion was satisfied. However, this connection to nanotechnology is more implied than explicitly stated, so the user may not be completely aware of the connection."
4	"One potential weakness of this section is that the relationship to nanotechnology may be somewhat abstract for students, making it difficult for them to grasp at first."
7	"Our program could still be vastly improved to tie in the nanotechnology relationship more strongly."
12	"Weaknesses include not mentioning what they are interacting with is nanotechnology."
13	"A weakness of this criterion is that the program does not involve all nanotechnology concepts."
14	"We are strong in the fact that this model helps teach students important laws that relate to nanotechnology. We are weak in the fact that we don't describe in the program exactly how the Gas Laws relate to nanotechnology."
23	"A weakness of our activity is that even though we state that the Law of Conservation of Energy can be applied in all situations, we do not present multiple scenarios in which it can be applied."
26	"…our solution does not have too much to do with nanotechnology."

Most teams (4 out of 6; Teams: 5, 10, 11, & 16) that did not discuss a specific nanotechnology product or application and did not confess to having a weakness in addressing Criterion 1, stated that the team incorporated nanotechnology in their project through text "blurbs" or "pop-ups" in their graphical user interface (GUI). The remaining two teams (Teams: 9 & 15) justified that their projects sufficiently taught about nanotechnology because the team taught foundational knowledge since one needed to understand concepts at the macrolevel before the nanoscale can be introduced and the team's topic of material properties started with reactions between atoms even though this is not what the GUI focused on.

E. Project Science and Math Concepts

Two of the given criteria (Criteria: 2 & 3) were to relate the project to at least one science and mathematics concept standard for 11th or 12th grade students. Physics topics were the most selected, chemistry topics were the second most selected, and biology was the least selected science topic (Table 8). Science concepts were discussed by 27 out of 28 teams (all except Team 8) and mathematics concepts were discussed by 24 out of 28 teams (all except Teams: 2, 10, 18, & 28). Some teams discussed multiple topics within a selected science concept (Physics, Chemistry, or Biology), but only Team 20 discussed topics within two science concepts (Physics & Chemistry).

Table 8. Science and Math Concepts Related to Projects

11 & 12 Grade Concepts		Specific Topics Discussed (listed most to least frequently selected topic)	Teams Discussed	# of Teams
Science	Physics	Kinetic & Potential Energy, Newton's Law, Law of Conservation of Energy, Forces, Light Properties, Material Properties, Ohm's Law, Electricity Properties, Velocity & Acceleration	1 – 3, 13, 15 – 18, 20, 23, 26, 27	13
	Chemistry	Ideal Gas Law, Stoichiometry, Atomic Properties, Molecules, Titration, Hybridization	4, 5, 9, 14, 19 – 21, 25, 28	9
	Biology	Genetics, Photosynthesis, Cell Characteristics, Bacteria Growth, Cell Division	6, 7, 10 – 12, 24	6
Mathematics		Algebraic Problem Solving, Graphing & Plotting, Word Problems, Variable Manipulation, Geometry, Exponential Growth, Linear Equations, Calculus (Derivatives), Probability	all except 2, 10, 18, 28	24

Team 8 was the only team that only related their project to mathematics; this team related their project to nanosensors and nanowires. Out of the 27 remaining teams, 12 teams related their project to some type of nanotechnology example (Table 5). Team 20 related their project to carbon nanotubes and two science concepts (Physics & Chemistry). Team 22 related their project to Physics and two nanotechnology examples (nanotubes & nanowires). The majority of teams that related their projects to Chemistry concepts also discussed an example of nanotechnology; nanoparticles were the most commonly discussed (Table 9). Teams that related their project to biology had the least relation to a nanotechnology application (Table 9). The teams that related their project to Physics had the most variation of discussed technologies (Table 9).

Table 9. Science Concepts related to Nanotechnology Examples

Science Concept	# of Teams (mentioned a specific example of nanotechnology)	**Technology Discussed** (team # that discussed it)
Physics	7 out of 13	nanotubes (18, 20, 22), nanoparticles (27), circuits (2), nanowires (22), quantum dots (1), nanofabric (17)
Chemistry	5 out of 9	nanoparticles (19, 21, 25, 28), nanotubes (20)
Biology	2 out of 6	solar panels (24), nanobots (6)

V. Discussion

The results show that student teams had difficulty: (1) defining nanotechnology and its scale, (2) describing products and applications of nanotechnology, and (3) relating nanotechnology to high school science and mathematics standards.

The students' difficulty in understanding the nanoscale is evidenced by their mention of many other scales in relation to nanotechnology, some teams' explicit definitions of nanotechnology on other scales, and the inability of the majority of the teams to quantify the nanoscale. This is a common problem that students face when studying nanotechnology, but it is also a fundamental concept that needs to be understood.[11-13] Since being able to define nanotechnology and the nanoscale are important but lacking, this should be part of a new criteria list that is more focused on nanotechnology aspects of the design project. This specific criterion could replace the more vague criteria given in Criterion 1 (clearly show how the rationale for this project will help students learn nanotechnology). Computer graphics, visualized sizing charts, and educational videos are some techniques that have been found effective at helping students understand the nanoscale.[11-13] The nanoHUB website has many videos, visualizations, animations, and other interactive tools that can be utilized to help students learn about the nanoscale. In a future implementation, there will be a stronger introduction to the scale of nanotechnology and more assignments that direct students to use the online resources. It is evident that more scaffolding will be necessary to enable students to successfully learn about nanotechnology from the partner's vast resources.

Within the projects, students that discussed a specific nanotechnology application or product appear to have done a better job of fulfilling Criterion 1. A connection of a product or application could also help students define nanotechnology beyond the understanding of just the nanoscale itself. Extant literature suggests that students that learned about nanotechnology in the classroom typically learned about the nanoscale and did not connect nanotechnology to products.[3] For these two reasons another criterion should require that students pick a specific nanotechnology product or application to incorporate in their project.

The third shortcoming of students' projects of relating nanotechnology to high school science and mathematics standards is already partially in the given criteria (Criterion 2: clearly address one state science standard for the targeted grade level and Criterion 3: clearly connect the science or engineering topic to math activities that are appropriate for the targeted grade). These criteria address the need for the students to incorporate a mathematics and science topic, but do not address relating nanotechnology to the topic. The current requirement for students to try to teach high school students nanotechnology through selected science and mathematics topics does not seem to be an effective project setting, especially in terms of trying to help students understand that some properties change on the nanoscale. The project setting should be refocused to modeling and computations, which is also more in line with the project partner's mission statement. A project setting focused on the importance of computational modeling because of the property changes could help enable students to understand this important aspect of nanotechnology.

VI. Conclusions

In assigning projects to help students begin to explore nanotechnology, two aspects that the instructors should clearly establish are: (1) the definition of nanotechnology, including the nanoscale and property changes, and (2) relevant applications, products, or technologies. Scaffolding nanotechnology specific topics is a necessary component in projects for students to successfully learn about nanotechnology.

This study only looks at student teams' executive summaries; an examination of the projects themselves may reveal that a greater number of teams incorporated nanotechnology more successfully than students were able to convey in their summaries. A full investigation into whether teams had greater success than communicated in executive summaries may be helpful in understanding the specific cases, but for a greater understanding of what proved successful should be of greater importance. A case study should be completed on select teams to better understand the details of their project. Since a primary focus of the project was relating nanotechnology to three different science topics and mathematics, the best option would probably be to analyze four teams' full projects that involve a product in detail, one for each topic. A list of selected teams that should be analyzed are given in Table 10.

Table 10. Potential Teams for a Case Study

Team #	Educational Topic	Product
17	Physics	Nanofabric
20	Chemistry	Nanotubes
6	Biology	Nanobots
8	Mathematics	Nanosensors & Nanowires

This study looks at the various teams without any grouping based on gender; a future gender study should be completed because females and males were found to have different perspectives of nanotechnology.[3] Since the design projects only address the knowledge teams are gaining, a pre-post assessment using a modified Nanotechnology Awareness Survey[2] will be incorporated in the class to understand each individual's awareness, exposure, and motivation concerning nanotechnology. To increase the exposure students have to nanotechnology, the research team will couple the nanotechnology design project with another project based on nanotechnology. The implementation of a mathematical modeling project regarding nanotechnology measurements[9,16] will be implemented at the beginning of the semester to compliment the revised design project.

Acknowledgements

This work was made possible by a grant from the National Science Foundation (NSF EEC 1227110). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

Bibliography

1. Diefes-Dux, H. A., Dyehouse, M., Bennett, D., & Imbrie, P. K. (2007). Nanotechnology awareness of first-year food and agriculture students following a brief exposure. *Journal of Natural Resources and Life Sciences Education*, *36*, 58-65.
2. Dyehouse, M., Diefes-Dux, H. A., Bennett, D., & 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.
3. Lu, K. (2009). A study of engineering freshmen regarding nanotechnology understanding. *Journal of STEM Education : Innovations and Research, 10*(1), 7-16. Retrieved from http://search.proquest.com/docview/222790119?accountid=13360.
4. Castellini, O. M., Walejko, G. K., Holladay, C. E., Theim, T. J., Zenner, G. M., & Crone, W. C. (2007). Nanotechnology and the public: Effectively communicating nanoscale science and engineering concepts. *Journal of Nanoparticle Research*, *9*(2), 183-189.
5. Foster, L. E. (2005). *Nanotechnology: Science, Innovation, and Opportunity*, Upper Saddle River, NJ: Prentice Hall.
6. Lux research; nanotechnology-based products starting to have big consumer impact. (2004). *Biotech Week,* 469-469. Retrieved from http://search.proquest.com/docview/205591298?accountid=13360.

7. Mahbub Uddin,M., & Chowdhury, A. R. (2001). Integration of nanotechnology into the undergraduate engineering curriculum. *Proceedings of the International Conference on Engineering Education, Oslo, Norway.*
8. Clark, A. C. & Ernest, J. V. (2005). Supporting technological literacy through the integration of engineering, mathematic, scientific, and tecchnological concepts. *Published Proceedings of the 2005 ASEE Annual Confernce & Exposition, Session 146*. Chicago, IL.
9. Diefes-Dux, H. A., Imbrie, P. K., Haghighi, K., Lee, G., Wereley, S., and Wankat, P. (2004). Nanotechnology exporsure in a first-year engineering program. *International Conference of Enginering Education and Research "Progress Through Partnership" ISSN 1562-3580.* Ostrava.
10. Mathworks. (1994-2012). Retrieved from: http://www.mathworks.com.
11. Nanoscale Informal Science Education (NISE) network. (2012). Retrieved from: http://www.whatisnano.org/.
12. Jones, M. G., Andre, T., Superfine, R., and Taylor, R. (2003). Learning at the nanoscale: The impace of studennts' use of remote microscopy on concepts of viruses, scale, and microscopy. *Journal of Research in Science Teaching*, *40*(3), 303-322.
13. Weibe, E. N., Clark, A. C., Ferzli, M., and McBroom, R. (2003). The VisTE Project: Visualization for improved technological and scientific literacy. *Published Proceedings of the 2003 ASEE Annual Conference & Exposition, Session 2438*. Nashville, TN.
14. Roco, M. D. (2002). Nanoscale science and engienering educaiton activities in the United States. *Jounral of Nanoparticle Research*, *4*, 271-274.
15. Goonewardene, A. U, Offutt, C., Whitling, J., and Woodhouse, D. (2012). Engaging undergraduate through interdisciplinary research in nanotechnology. *Journal of College Science Teaching*, *41*(3), 36-41.
16. Moore, T. J., & Hjalmarson, M. A. (2010). Developing measures of roughness: Problem solving as a method to document student thinking in engineering. *Journal of Engineeirng Education, 26*(4), 820-830.
17. Kim, D., Kamoua, R., and Pacelli, A. (2005). Design-oriented introducation of nanotechnology into the electrical and computer engineering curriculum. *Journal of Educational Technological Systems, 34*(2), 155-164.
18. Duncan, K. A., Johnson, C., McElhinny, K., Ng, S., Cadwell, K. D., Zenner Petersen, G. M., Johnson, A., Horoszewski, D., Gentry, K., Lisensky, G., Crone, W. C. (2010). Art as an avenue to science literacy: Teaching nanotechnology through stained glass. *Journal of Chemical Education, 87*(10), 1031-1038.
19. Patton, Michael Q. (2002). Qualitative research and evaluation methods. Thousand Oaks, CA: Sage Publications, Inc.
20. Rodgers, K. J., Diefes-Dux, H. A., and Cardella, M. E. (2012). The nature of peer feedback from first-year engineering students on open-ended mathematical modeling problems. *Published Proceedings of the 2012 ASEE Annual Conference & Exposition.* San Antonio, TX.
21. Aiyagari, N. & La Breche, T. (1997). Environmental samplig & monitoring primer. Retreived from: http://www.webapps.cee.vt.edu/ewr/environmental/teach/smprimer/immuno/immuno.html.