First-Year Engineering Students Explore Nanotechnology in Engineering

K. J. Rodgers
Graduate Research Assistant
Purdue University
West Lafayette, United States
E-mail: krodger@purdue.edu

H. A. Diefes-Dux
Full Professor
Purdue University
West Lafayette, United States
E-mail: hdiefes@purdue.edu

K. Madhavan
Assistant Professor
Purdue University
West Lafayette, United States
E-mail: cm@purdue.edu

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INTRODUCTION

Innovations in nanotechnology are greatly improving the quality of everyday life and impacting most science and technology fields [1]. The number of nanotechnology products and workers has skyrocketed over the past decade and are still continuing to grow; trends suggest that by 2020 there will be a 3 trillion dollar market with 6 million workers [1]. Although nanotechnology is a promising field for advancement with significantly increasing funding, there is an insufficient number of engineers informed about nanotechnology and prepared to enter this field [1,2].

Training and education are critical for preparing workers to enter into nanotechnology research & development and production [1]. To prepare engineering students for nanotechnology research, there needs be a strong collaboration between industry, researchers, and academics [3,4]. Nanotechnology education should focus on integrating disciplines to promote multidisciplinary teaming, while still teaching students depth in a single discipline [1]. Understanding nanotechnology in one's own field of study is a clear foundational need for students to achieve multidisciplinary teaming skills, while developing understanding in their own field. Kennedy (2006) clearly establishes how nanotechnology relates to multiple engineering disciplines

[4], but it is important to investigate whether engineering students are capable of making this connection as well. This study is aligned with other research that calls for understanding students' perspectives of nanotechnology as a means to reform college programs and advance nanotechnology education [5].

The research questions that guide this study are as follows:

1. What engineering fields of study do first-year engineering students investigate in a nanotechnology-related assignment?
2. Do first-year engineering students demonstrate awareness of nanotechnology related to their intended field of study?

This is the first in a series of studies investigating what students learn from engaging in nanotechnology-based project work in first-year engineering. Nanotechnology is acknowledged to be an interdisciplinary and multidisciplinary field. The purpose of investigating these research questions is to understand whether first-year engineering students can find connections between nanotechnology and their potential engineering field of study. It is anticipated that this opportunity for individual research of nanotechnology will promote substantial nanotechnology content knowledge acquisition and further exploration.

1 LITERATURE REVIEW

1.1 Nanotechnology Education

Previous research conducted on nanotechnology education identified four key categories of content knowledge and skills needed in the field: 1. nanoscale concepts, 2. nanoscale critical thinking, 3. nanoscale tactile, and 4. nanoscale soft skills [3]. The category of nanoscale concepts requires one to have a sense of the nanoscale itself, along with an understanding of surface area and volume, forces and interactions, and material properties at the nanoscale [3]. Nanoscale critical thinking suggests that one should be able to apply traditional engineering problem solving and design skills to nanoscale problems [3]. The nanoscale tactile category encompasses nanotechnology-specific knowledge about equipment, safety, maintenance, and other topics related to the nanotechnology work-environment [3]. Finally, the nanotechnology soft skills category refers to professionalism, collaboration, and educational growth (e.g., communication, teaming, life-long learning) [3].

The second and fourth category of nanoscale critical thinking and soft skills are aligned with the United States accreditation program outcomes requirements for engineering [6]. This alignment makes engineering an easily adapted environment for preparing a future nanotechnology workforce. The greatest difference between nanotechnology and engineering education is the acquisition of the nanotechnology-specific content knowledge.

Another perspective that discusses the "big ideas" of nanotechnology is the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) and National Science Teachers Association (NSTA). The big ideas that NSTA discusses include size & scale and tools & instrumentation [7], similar to what Fazzaro et. al. (2012) discuss in their first and third categories. Beyond these two big ideas, the NSTA discuss seven additional big ideas: 1. size-dependent properties, 2. structure of matter, 3. forces & interaction, 4. self-assembly, 5. quantum effects, 6. models & simulations, and 7. science, technology, & society [7]. The first five big ideas discuss the different scientific understanding that is required on the nanoscale. The sixth big idea about models & simulations discusses the importance of modeling to help scientists visualize, explain, and predict what is happening on the nanoscale [7]. Modeling and computational design are fundamental in determining ways of better control some of the property changes and developing new molecules to further develop nanotechnology products [1]. This need for computational modeling and simulation is a reason why nanoHUB.org [8] is a fundamental platform for conducting and disseminating nanotechnology research. The seventh big idea of science, technology, & society addresses the concept of understanding the potential and importance of nanotechnology [7]. This last big idea focuses on nanotechnology awareness, which is fundamental for student engagement [2].

1.2 Nanotechnology in First-Year Engineering

Nanotechnology is a promising topic for first-year engineering students as it enables students to have opportunities to learn about multidisciplinary and interdisciplinary contexts for engineering [2,5]. Integrating nanotechnology in first-year engineering may also help reduce the first to second year dropout rate by involving students in real world problems with tangible societal impact [5]. A survey taken by first-year engineering students showed that 93% agreed or strongly agreed with the idea that nanotechnology will change the American way of life [5]. Furthermore, 91% agreed or strongly agreed that nanotechnology will be a huge and important industry in the future [5]. The majority of students acknowledge that nanotechnology is fundamental for technological advancement of our future, demonstrating their belief that nanotechnology is impacting society. Implementation of nanotechnology can help engage students in a topic that believe to be substantial and tangible.

Introducing students to nanotechnology early in their education is essential because nanotechnology acceptance and understanding are the foundation for nanotechnology advancement [5]. It is important to acknowledge that there is ideal content knowledge to target in nanotechnology education [3,7]. Understanding the nanoscale is one concept that students need to grasp [3,7]. Although knowledge of the nanoscale is important, it is also important to connect the scale of nanotechnology to its applications to create and maintain an engaging learning environment. Previous research has found that when nanotechnology is taught in classrooms students typically learn about scale, but they do not connect nanotechnology with its current and potential applications [5]. This is a reminder that it is important to find balance between teaching students about theoretical concepts and real-world applications in nanotechnology education.

There has been some previous research concerning the implementation of nanotechnology curricula in first-year engineering and upper levels of undergraduate studies. One prior study conducted in first-year engineering focused on the nature of teams' solutions in a nanotechnology-based design project [9]. It was found that more successful teams connected their project to a specific nanotechnology application and implicitly or explicitly a discipline of engineering [9]. Model-Eliciting Activities (MEAs) provide another means of introducing students to nanotechnology concepts [10]. The Nanoroughness MEA enables students to learn about nanoscale measurement equipment (i.e. atomic force microscopy), while helping them build other engineering skills (e.g., critical thinking, teaming, and effective communication skills) [10]. Effectively incorporating these projects into multidisciplinary environments should present some opportunity for depth in one's own field along with the presented breadth of the topic. The goal of this study is to understand the potential for this depth of understanding before addressing the multidisciplinary teaming and broad knowledge elements.

2 METHOD

2.1 Setting and Participants

This study focuses on the problem scoping that comes prior to solving authentic engineering problems. First-year engineering students' gained awareness and understanding of nanotechnology is investigated through their responses to prompted individual research outside of the classroom. The setting of this study is a required first-year engineering course that is part of Purdue University's First-Year Engineering (FYE) Program, which is the entry point for all incoming engineering students. This first-year engineering course utilizes course projects (e.g., design projects and MEAs) and online resources (e.g., nanoHUB.org) to increase understanding of and broaden participation in nanotechnology.

All students in the FYE Program are required to complete two sequential 2-credit hour courses that focus on learning objectives associated with development of skills in teaming, problem-solving, designing, and utilizing computer tools (e.g. Excel, MATLAB). In Spring 2013, approximately 1650 students were enrolled in 14 sections (up to 120 students per section) of the FYE Program's second semester course. In this course, two team projects that utilize discovery learning principles were implemented. All sections completed the first nanotechnology-based project and six sections completed a second nanotechnology-based design project (the remaining sections worked on a number of different design projects). This study focuses on student work completed within the six sections that completed both nanotechnology-based projects. The first project was an open-ended, mathematical modeling problem that challenged students to develop a quantitative measurement of roughness for biomedical nanoscale surfaces, using atomic-force microscopy (AFM) images [11]. The second project challenged students to design an interactive graphical-user interface to engage peers in learning about two or more "big ideas" in nanoscience and relate these ideas to one or more field/s of engineering through models or simulations [9].

Prior to beginning these projects, students were to individually investigate nanotechnology and its applications in their own engineering field of interest. The intention of this context setting assignment was to raise awareness of how nanotechnology is affecting all fields of engineering, no matter how unlikely it might seem to students. The assignment read as follows:

"Nanoscience and nanotechnology is impacting every field of engineering. Use and document (with proper citations) at least two external and trustworthy resources to learn three things about how nanotechnology is impacting your intended field of study in engineering. …list, in your own words, the three things you learned about nanotechnology."

The students' responses for this context setting assignment were analysed for all 619 students from the six sections. Out of the 619 students, 28 students did not complete this assignment, 7 students seemed to not understand the question, and 38 students did not state their engineering field of interest. Out of the remaining 552 students, 15 students indicated more than one field of study. Seven of these students listed two potential fields that they were interested in, six students listed two fields that they intended to complete (e.g. dual major), and five students listed a major field of study with a focus in a second field (i.e. "emphasis", "focus", or "minor). This analysis focuses on the responses of the 537 students who indicated one intended field of study.

2.2 Data Analyses

Student responses to the context assignment were first analysed using a qualitative approach to elicit patterns. Each response was parsed into two categories: intended engineering field and nanotechnology-focused content (i.e. facts, applications, products, and potential effects to consider). The intended engineering fields were categorized and the nanotechnology content was evaluated as either focused on their intended field or not. The results were quantified to enumerate the frequency of types of fields and their connections to nanotechnology. Some examples of the nanotechnology-focused content that students discussed are provided in the results. This analysis transforms qualitative data into quantitative data to enable quantitative analysis [11].

3 RESULTS

The 537 students focused on 14 engineering fields. The 14 engineering fields of study that these students focused on consisted of: Aeronautics and Astronautics, Agricultural and Biological, Biomedical, Chemical, Civil, Construction and Management, Electrical and Computer, Electrical, Environmental and Ecological, Industrial, Materials, Mechanical, Multidisciplinary, and Nuclear. All of these 537 student responses are shown in *Figure 1*.

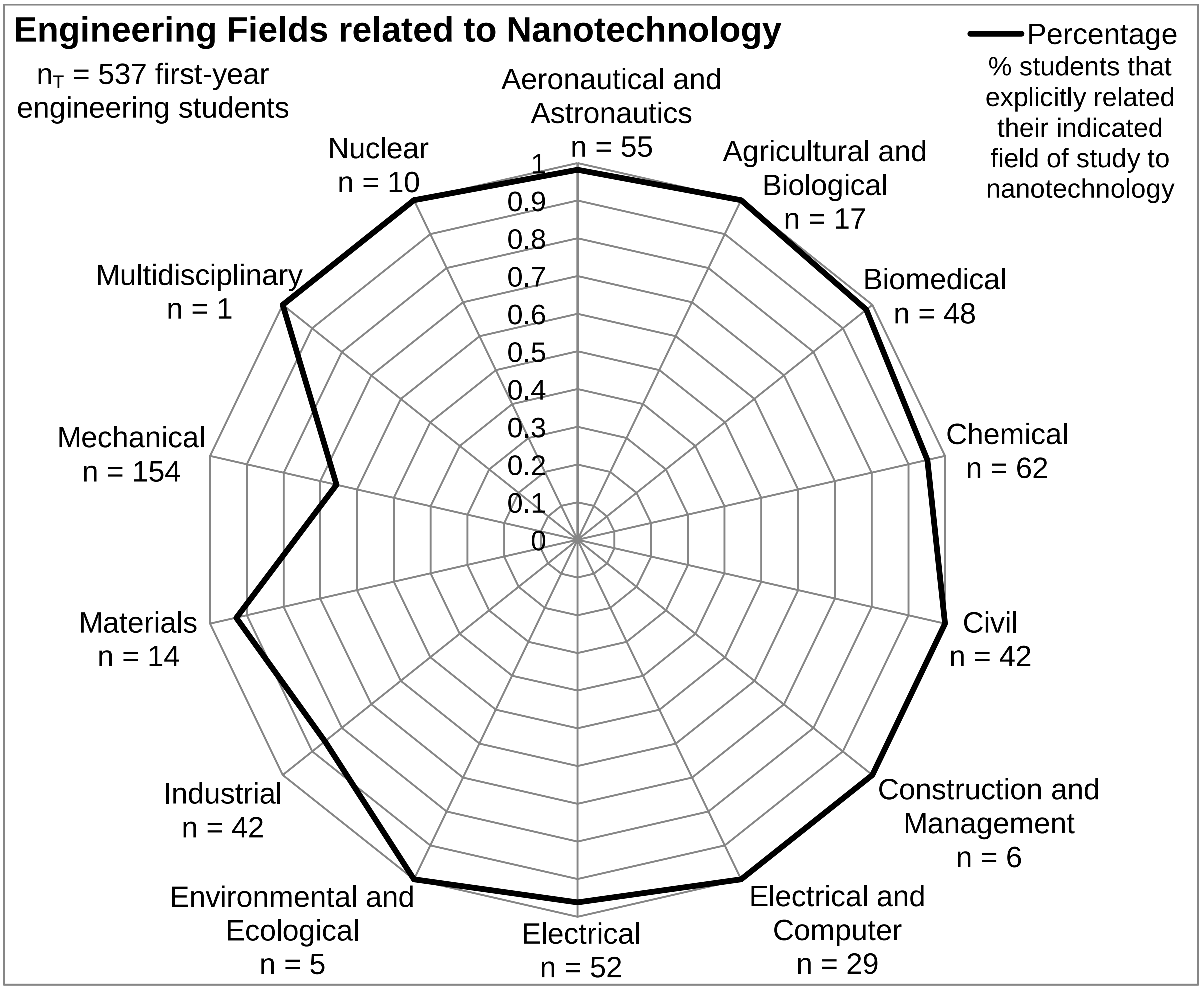

Fig. 1. Engineering Students' Responses to Context Setting Assignment

Figure 1 shows the number of students who indicated each field of study and the per cent who related nanotechnology to their intended field. With the exception of Mechanical and Industrial Engineering, more than 90% of students successfully related nanotechnology to their intended field of study. Only 65% of students who intended to enter Mechanical Engineering and 86% of students who intended to enter Industrial Engineering successfully discussed how nanotechnology would impact their field.

Partial examples of responses, where students effectively connected nanotechnology to their intended field of study follow:

Biomedical: "I learned that nature and biology has been working on the nano-scale for as long as we have been around, for example DNA and hemoglobin, two essential molecules for human life, are about 2-5.5 nm in width and length respectively. I also learned that because surface area exponentially increases as things get smaller, nanoscaled objects can be used as catalyzers whether in the human body."

Civil: "Another thing is that nanotechnology is helping the production of a polymer that will act as a healing agent for roads and maybe bridges."

Nuclear: "Another way nanotechnology is being used in nuclear application is for cooling. Nano-particles have a greater ability to absorb heat and therefor work better as a coolant."

The students that did not focus on how nanotechnology affects their field of study either discussed how nanotechnology is affecting other fields or provided facts about nanotechnology. Out of the 67 students that did not explicitly connect nanotechnology to their intended field, half of the students (n=34) discussed applications and effects of nanotechnology in fields other than their own; the other half of the students discussed this along with nanotechnology facts (n=27) or only facts about nanotechnology (n=6). The students that discussed nanotechnology connected to other fields, either connected it to one field (n=19), two fields (n=20), three fields (n=15), or four fields (n=7). The engineering fields that more than 11 students discussed were: Biomedical (n=32), Materials (n=28), Industrial (n=15), and Environmental and Ecological (n=14). For examples:

Industrial: "Uses [of] nanofibers are explored in fields as diverse as medicine filtration systems, clothing, air and water and electric batteries."

Mechanical: "Nanotechnology is contributing to the development of improved materials based on properties observed at the nanoscale (1-100 nanometers)."

The first student does not explicitly indicate how industrial engineering and the stated applications of nanotechnology are connected. The second student defines the nanoscale and an impact of nanotechnology.

4 DISCUSSION

Students were able to relate all fields of engineering offered at Purdue University to nanotechnology. At least one student for every field of study represented connected their field of study to a nanotechnology application, product, and/or potential effect. This analysis of students' responses shows an example of how nanotechnology can be a platform for studying various fields of engineering within a common field, nanotechnology. Although some students did not explicitly focus on their intended field of study, they still demonstrated nanotechnology awareness and/or understanding of how nanotechnology is impacting engineering. Some students discussed a more global perspective of how nanotechnology influences various engineering fields. Future mechanical engineering students did this most commonly; they may have had the most diverse responses about nanotechnology that targeted other fields of study or more broad topics because mechanical engineering is acknowledged to be a diverse field of study that many engineers branch into other fields of study from. The students' explorations of nanotechnology related to their intended field that resulted in a discussion of another field of study may show students' misunderstanding of their intended field and/or interest in another field of study. This assignment presented an opportunity for students to explore nanotechnology while connecting it to their field of study or other fields of study. This was as an effective method for enabling students to explore nanotechnology applications to improve their understanding and/or awareness of nanotechnology and its potential in engineering. Only about one per cent of students only discussed facts about nanotechnology, so the majority of students were able to successfully discuss nanotechnology applications and/or products explicitly related to a field of engineering.

5 CONCLUSION

First-year engineering students, who have little awareness of nanotechnology, show an ability to increase their awareness and understanding of nanotechnology through prompted individual research. This study shows that the majority of engineering students can connect nanotechnology to their intended field and demonstrate an understanding of how nanotechnology is impacting their field of study. Nanotechnology's connection to various engineering fields may be an engaging method of introducing and increasing engineers' awareness and understanding of nanotechnology; this should be considered in on-going development of the educational site of nanoHUB.org. Students' level of awareness can be measured throughout investigation of this topic with an already validated tool [2]. This tool could also be further developed to measure students' level of nanotechnology understanding.

The clustering of students from various engineering disciplines within first-year engineering appears to be an effective platform for investigating multidisciplinary teaming. Research has commonly reported that nanotechnology is a multidisciplinary field and impacts all disciplines of engineering [4], but there is not a lot of research that characterizes the nature of multidisciplinary teaming required for nanotechnology work [12]. Chari, Howard, and Bowe (2012) conducted a phenomenological study to understand the nature of this field from the post doctorates' perspective in their nanotechnology research [12]. The study presented here lays the foundation for additional studies into the nature of multidisciplinary teaming during nanotechnology-based projects.

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