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# No Small Feat: Building A Nanoscience and Nanotechnology Program for Engineering Undergraduate Students

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# No Small Feat: Building a Nanoscience and Nanotechnology Program for Engineering Undergraduate Students

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**Abstract**

Recent advances in nanoscience and nanotechnology (NSNT) have resulted in the development of new civil and military applications as well as many new commercial opportunities. These opportunities have led to the development of products and industries that hold the potential for significant economic and societal benefits. According to Lux Research, an emerging technologies consulting firm, the estimated total (public and private) global nanotechnology funding for 2012 was approximately $18.5 billion.

Therefore, an urgent need exists for training a workforce in NSNT. Since 2000, countries have invested billions of dollars in research/development and education to advance nanoscale science, engineering, and technology. Despite these efforts, nanotechnology and nanoscience programs exist in a handful universities around the world.

At the University of North Dakota (UND), a mid-size research institution in the Midwest and one of two research universities located in the state of North Dakota, there were no regularly designated courses to educate undergraduate students in nanoscience and nanotechnology until 2014. This paper will describe an NSF-funded project to establish a nanoscience and nanotechnology program at UND with the goal of generating new interest in nanoscience and nanotechnology among STEM students and prepare them with the knowledge and skills necessary for the next generation of graduates to compete in the global market and contribute to the NSNT field.

The outcomes of the project are: 1) creation of two courses that expose STEM students to nanoscience and nanotechnology, 2) development of several hands-on activities to train the future workforce and increase its expertise in nanoscience and nanotechnology, and 3) Facilitation of outreach activities for underrepresented groups to expose students from tribal colleges in the state of North Dakota to NSNT. The first course was taught in the fall 2015 semester and the second course is being taught in the spring 2016 semester. The two courses cover basic nanoscience and nanotechnology concepts and the impact of NSNT and its importance on future societal and economic development.

## I Introduction

Nanoscience and nanotechnology, along with their associated infrastructure, are essential learning in many international academic and industry sectors [1-9]. Countries are now in the midst of a race to acquire the next generation of technologies for utilizing nanoscience in various engineering applications. Extensive Research and Development (R&D) efforts currently aim at drawing a new map of cutting-edge global technology powers [8-9]. Recent advances in nanoscience and nanotechnology have resulted in the development of new civil and military applications and commercial opportunities. These opportunities have led to the development of products and industries that hold the potential for significant economic and societal benefits. Since 2000, countries have invested billions of dollars in Research/Development and education to advance nanoscale science, engineering, and technology. According to Lux Research, an emerging technologies consulting firm, the estimated total (public and private) global nanotechnology funding for 2012 was approximately $18.5 billion [14]. Despite all these efforts, nanotechnology and nanoscience (NSNT) programs exist at only a handful of universities in the United States and around the world.

In North Dakota, NSNT is still an under-developed academic field. At the University of North Dakota (UND), one of two research universities located in North Dakota, there are no regularly designated courses to educate undergraduate students in nanoscience and nanotechnology. The development of NSNT is one of the main goals in the strategic plan of UND. Developing NSNT courses is essential to meeting the needs of industry in the region – and beyond – to provide much needed education and training for engineers.

This paper describes an NSF-funded project to establish a nanoscience and nanotechnology (NSNT) program at UND. The project aims to foster new interest in nanoscience and nanotechnology among UND STEM students from a multidisciplinary perspective. Faculty from Electrical Engineering, Mechanical Engineering, Chemical Engineering, Chemistry, and Physics are actively involved in preparing and delivering the NSNT course content. This approach encourages collaborative and multidisciplinary learning for the students and helps them acquire the knowledge and skills necessary to compete in the global market and to contribute to the NSNT field in an environment that is reflective of today’s workplace.

## II Courses

For this project, the collaborators developed and offered two NSNT courses that satisfy elective requirements for mechanical, chemical, and electrical engineering Bachelor of Science (BS) degrees as well as for chemistry and physics BS degrees. The first course, “Nanoengineering and Nanoscience” (cross-listed course numbers: CHEM 431; EE490; ME490; PHYS492) was offered during Fall 2015. It covered the fundamentals of nanoscience and nanoparticles based on their physical and electronic structures.

To increase students' learning, two teaching methods were used: case studies and problem-based learning (PBL). These methods were well-suited for teaching prospective scientists and engineers because they focus on cooperative sharing of ideas as well as healthy discussion and resolution of problematic issues [10, 11]. PBL-structured case studies promote higher-order learning skills, such as application, analysis, synthesis, and evaluation. During case study-based learning modules, students were presented with a selected case to resolve the core issue by critically evaluating the information they had researched. They had opportunities to find the latest developments in a field and associate them with most recent social issues. This approach overcame the weakness of traditional lecture-based learning modules which may quickly become out of date for rapidly changing areas like NSNT without diligent attention from well-informed instructors. By its nature, PBL-structured case studies promote learning at the cutting edge of a discipline and thus are well-suited to the emerging NSNT field.

A central premise in using the case study technique is that the process of learning is just as important as the content [12]. In general, students work cooperatively during case studies to answer challenging questions or to evaluate complex ethical issues. For PBL-structured case studies, students are expected to investigate and learn necessary content in order to understand the context of a case. This requires students to become more involved in the learning process and help them develop traits that are important for mature scientists and engineers. The collaboration inherent in case studies presents a challenge for students who excel as individuals in lecture courses [13]. Cooperative problem solving is an essential approach that professional scientists and engineers utilize in their jobs, therefore it is important that undergraduate students are versed in this approach.

The second course, "Engineering Applications of Nanoscience & Nanotechnology" (cross-listed course numbers: EE490/590; ME490; Chem431; PHYS 492) is currently offered this spring 2016. This course covers mechanical, electrical, and chemical properties of nanomaterials and engineering applications of nanoscience and nanotechnology. It also covers ethical, social, and environmental impacts of nanomaterials. The second course uses a combination of lecture and discussion in addition to case studies and problem-based learning.

The results pertaining to student knowledge are being analyzed and will be covered in a later publication. In addition, the collaborators are collecting data to determine students' interests in nanoscience and nanotechnology as a discipline and as a career field, as well as their attitudes toward the societal and economic impact of nanoscience and nanotechnology. Participating students are asked to complete a survey about their awareness of and attitude about nanotechnology, their motivation for studying nanotechnology, and what they currently know about nanoscience and nanotechnology. The survey will be administered to students twice: once at the beginning of the semester and once at the end of the semester. Data collection in this vein is ongoing.

## III Hands-on activities

As part of the NSF project and to increase student learning, several lab activities were integrated into the first course. The objective of these activities was to introduce students to the optical properties of gold nanoparticles that can be changed dramatically as the size of the nanoparticles varies. Throughout these experiments, students learned the difference in properties between nanomaterials and bulk materials. To measure the properties of nanomaterials, students learned how to use the Scanning Tunneling Microscope (STM) and the Atomic Force Microscopy (AFM) instruments. Examples of these lab activities are described below.

**Characterization of the nanoparticle using SEM**

The size of the obtained nanoparticles was 50±3 nm in diameter, which were readily observed under a scanning electron microscope (SEM). SEM was not the ideal instrument for measuring that size with accuracy, but SEM images can show shapes and approximate sizes of the nanoparticles. If the polymerization reaction works well, the shape of the nanoparticles will be perfectly spherical. RuBpy doped silica nanoparticles were synthesized and characterized using a SEM by undergraduates in this activity.

**Synthesis of gold nanoparticles**

The synthesis of gold nanoparticles has been well developed using a wet chemistry technique [28]. The reduction of hydrochloroauric acid ($HAuCl_4$) with sodium citrate generates colloidal gold nanoparticles. The nanoparticles were stabilized through a protective layer of citrate, chloride, and sodium ions. Different sizes of gold nanoparticles were synthesized by changing the reaction time while keeping all other conditions, such as the concentration of reactants and the reaction temperature. Due to the inherent limits of the resolution of the SEM, it was necessary to make the nanoparticles larger than 40 nm in order to observe the size differences clearly.

**Characterization of gold nanoparticles using SEM**

As described in Lab Activity 2, the synthesized gold nanoparticles were characterized using SEM to estimate their size and monodispersivity. These SEM derived sizes were then compared to the sizes predicted using UV-vis measurements.

**Characterization of gold nanoparticle optical properties using a spectrometer**

Different sizes of gold nanoparticles exhibit different peak absorption wavelengths in the visible wavelength range. Students explored the relationship between the gold nanoparticle size and peak absorption wavelength and made predictions of an average particle size based on their measurements. Comparing these results with direct size measurements made by SEM increased the likelihood that students better understood the inherent advantages and limitations of using the bulk spectroscopic method to characterize nanostructured materials.

## IV Outreach activities to tribal colleges

North Dakota has one of the highest concentrations of Native Americans and reservations in the United Sates. One important objective of the project is to expose Native American college and high school students participating in the Nurturing American Tribal Undergraduate Research and

Education (NATURE) program to nanoscience and nanotechnology through the Sunday Academy program. This program is designed to generate interest in math, science, and engineering programs among Native American high school students in the state of North Dakota. Once a month from September to March except for December, college tribal and high school students were brought together on Sunday and presented with practical day-to-day problems related to simple math, physics, chemistry, and engineering concepts in an informal, friendly atmosphere where they could learn, analyze problems, and seek viable solutions

To this end, the collaborators developed two activities and attended several NATURE program events. In the first activity, students learned the reasons why hair turns grey. They measured the diameter of human hairs and calculated the average and standard deviation in nanometer units. The materials needed are quite simple, only a laser point and a ruler were needed. In the second activity "discovering the properties of nanomaterials", students used an AFM to record an image of a CD-ROM. This allowed students to see how binary information is stored in this type of memory.

Like those who attend all NATURE Sunday Academy session, students who participated in the nanotechnology and nanoscience lessons were asked to provide feedback on their experiences. For example, students were asked to rate how interesting the topic was (response options ranged from "Hardly interesting" to "Extremely interesting"), how difficult the material was (response options ranged from "Too easy" to "Too complex"), the overall quality of the session (response options ranged from "Poor" to "Excellent"), and the extent to which participating in the hands-on activities added to the quality of the lesion (response options ranged from "Not at all" to "A lot"). Students were also given the opportunity to write additional comments about the activities.

Examples of results of the survey are shown in Figure 1. These results correspond to October 18, 2015, event. On that day, 15 students attended the lesson and the hands-on activities. Approximately 80% of attendees found the Sunday Academy topic on nanotechnology and nanoscience very or extremely interesting. Similarly, 80% thought that the level of difficulty of the nanotechnology and nanoscience lesson was just right. Over 93% of participants thought the quality of the lesson and activities was good, very good, or excellent. Finally, 87% of attendees thought that the nanotechnology and nanoscience hands-on activities added some quality to the lesson. Students' qualitative comments were not extensive, but they did express statements about the lesson that included: "I enjoyed listening to your lesson"; "Awesome"; "It was fun"; and "Thanks for teaching about more knowledge".

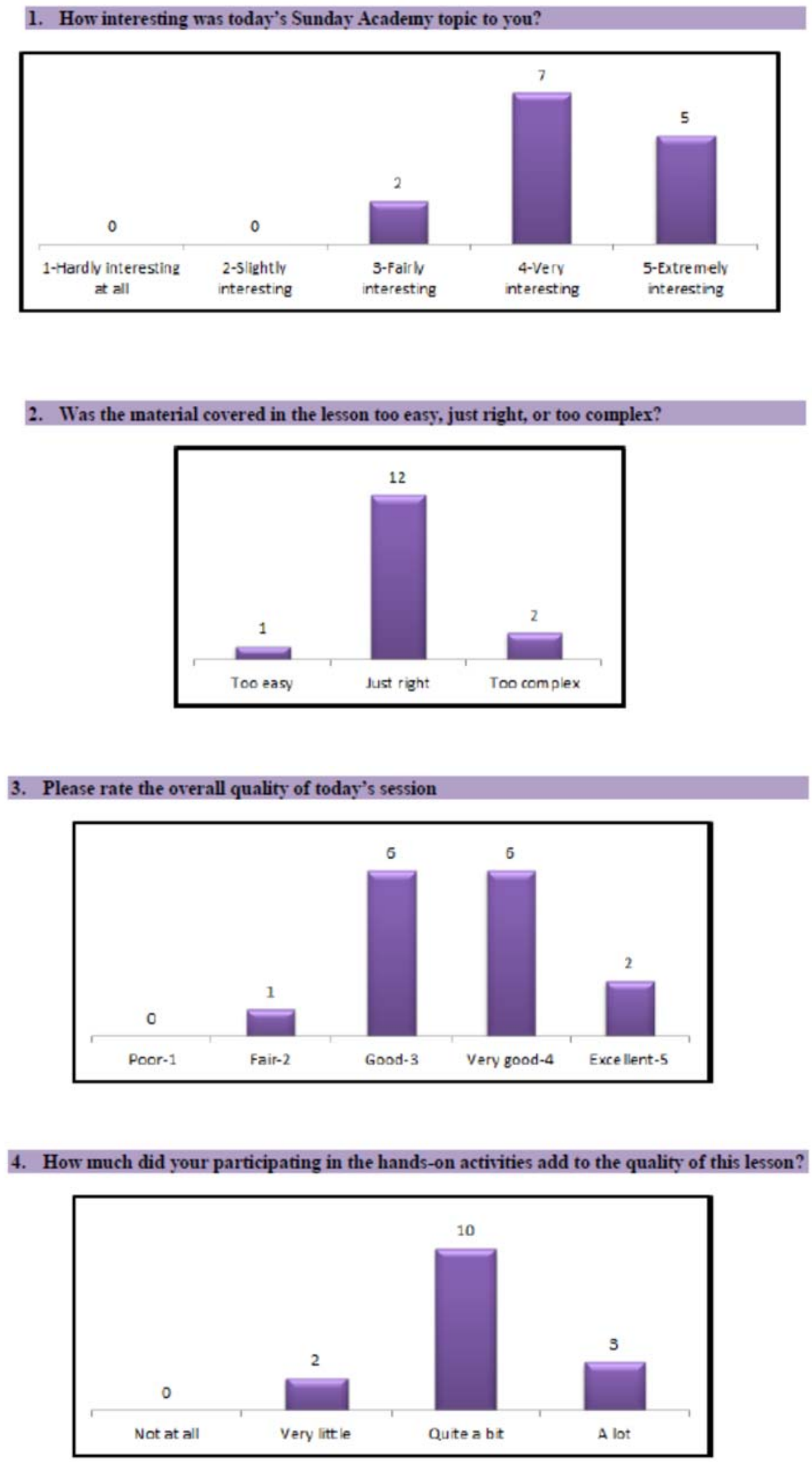


Figure 1: Results of Sunday Academy event of October 15, 2015.

## V Conclusions

In this paper, a NSF-funded project that aims to establish a nanoscience and nanotechnology program at the University of North Dakota was described. The project's aims are to foster new interest in nanoscience and nanotechnology among UND STEM students, provide them with the knowledge and skills necessary for the NSNT field, and prepare them to become the next generation of graduates to compete in the global market. In addition to courses, the collaborators developed and integrated hands-on activities in these courses for STEM students. Furthermore, Native American college and high school students participating in the NATURE program, were exposed to nanoscience and nanotechnology through the Sunday Academy program. The students completed survey after each event. The results of the surveys show that over 80% found the hands-on activities interesting and added quality to the lesson.

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