122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13595

# Enhancing Undergraduate Students' Learning and Research Experiences through Hands on Experiments on Bio-nanoengineering

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# Enhancing Undergraduate Students' Learning Experiences on Bio-nanoengineering

## INTRODUCTION

Nanotechnology is a revolutionary 21$^{st}$ century technology, and is starting to impact almost every aspect of society. Disease diagnosis and treatment is one high-impact area where nanotechnology has excellent potential and promise [1, 2]. Nanotechnology is already moving from being used as a passive structure in applications such as cosmetics and sunscreens to active structures in applications such as pharmaceuticals (targetable "smart drugs"). These new drug therapies have been shown to cause fewer side effects and to be more effective than traditional therapies [3]. Nanotechnology is also aiding in the formation of molecular systems that are designed to be noticeably similar to living systems, which could be the basis for the regeneration of body parts that are currently lost due to infection, accident, or disease [4-6]. In order to fully realize the promises of nanotechnology in medicine, significant improvements in scientific and technological infrastructure are needed as well as vast improvements in the education of technicians, engineers and researchers in the field.

The need for highly technically-trained and qualified nanotechnology workers with broad experience in the areas of engineering, biology and material science is estimated to be in the millions over the next two decades [3, 7]. To achieve this goal, continued investment and innovation in education is required from the K–12 levels through the professional level in order to enhance the understanding of the bio-nano interfaces [8, 9]. Such interdisciplinary education allows us to begin to predict the biological response to nanomaterials in order to more rationally develop materials such as diagnostic, therapeutic, imaging, and theranostic agents and implant materials [10]. Under the funding support from National Science Foundation-Nanotechnology Undergraduate Education (NUE) in Engineering we have developed a plan to enhance undergraduate student learning in bioengineering and provide students with research experiences, introducing them to the area of bio-nano devices and systems. Our plan integrates nanoscale technologies with biological systems in the development of new materials, biomimetic nanostructures, tools and devices that will facilitate biomedical research. Our emphasis is in the area of developing nanomaterials to improve clinical diagnostics and therapeutics, and to regenerate or improve tissue functions. This approach is expected to enhance student knowledge and understanding of bio-nano interfaces and proficiency in conducting research in the area of bio-nanoengineering. Students trained in this area are expected to earn a certificate in the interdisciplinary nanoengineering program which is under development as part of this project. The four primary objectives of our project are listed below:

I. To develop biomedical nanotechnology modules in existing bioengineering courses.
II. To develop a team-based, biomedical nanotechnology course with a significant hands-on laboratory component.
III. To develop a semester long research experience course related to biomedical nanotechnology for a limited number of undergraduates.
IV. To develop an interdisciplinary nanoengineering certificate program (INCP).

## ASSESSMENT METHODS & IRB APPROVAL

Each phase of the undergraduate student's learning experiences were assessed using multiple measurements. Content learning for Objective I, the learning modules in BMEN220 and BMEN310, was assessed using an instructor designed content assessment and student satisfaction was assessed using a student satisfaction survey. Content learning for Objective II, the course BMEN570, was assessed with a pre and post-test using an instructor designed content assessment and student satisfaction was assessed using focus groups. Content learning for Objective III, the course BMEN570, was assessed with a presentation review process involving 9 independent reviews, while course satisfaction was assessed using a student satisfaction survey. All assessments were administered by assessment personnel independent from the instructor and data were also analyzed by these personnel. All research was conducted in accordance with the policies of the Institutional Review Board (IRB), which granted approval for this research design and methodology.

## PROJECT ACTIVITIES AND OUTCOMES

I. Development and instruction of biomedical nanotechnology modules in existing bioengineering courses (Bio-Nano I).

Our first activity was to introduce concepts of biomedical nanotechnology in the form of modules and lectures in existing courses. Students were given the opportunity to learn how technologies inspired by Mother Nature, such as biological building blocks, their synthesis, and assembly in tissues and organs, are being used for the benefit of patients and doctors. To do this, we developed course modules for existing sophomore and junior-level courses in the undergraduate bioengineering curriculum (Table 1). The lecture content related to biomaterial for tissue engineering and ethics and nanobiotechnology techniques. Sample lecture content from the BMEN310 learning modules includes learning of hierarchical organization of extracellular matrix of bone and soft tissues in different length scales.

Table 1. Courses in which modules introducing the concepts of nanotechnology were developed

| **Course** | **Semester** | **# of students** | **Concepts Introduced Using two lectures** |
|---|---|---|---|
| BMEN 220: Introduction to Biomedical Engineering (Major: Bioengineering) | Fall 2013 and 2014 | 30 | Cellular engineering, drug delivery and nuclear medicine, ethics and nanomechanics |
| BMEN 310: Biomaterials Major: Bioengineering | Fall 2013 and 2014 | 19 | Nanoscale dimensions, tissue extracellular matrix, sub-cellular components and nano-biomaterials for tissue engineering |

Assessment and outcomes:

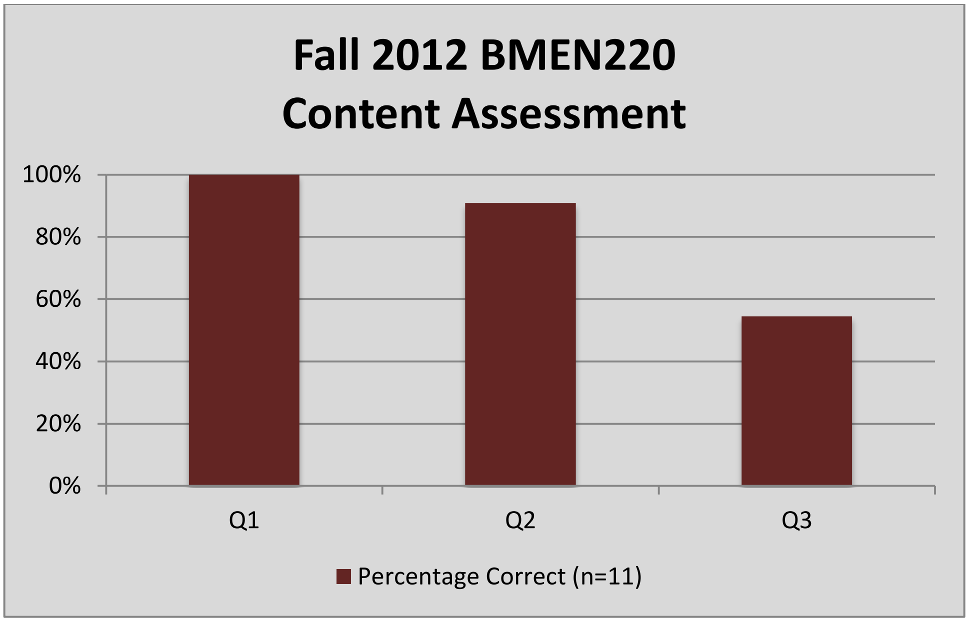
To assess the effectiveness of the content learning models, students were assessed on their content knowledge and satisfaction with the experience. Content knowledge from the learning modules was measured using a brief content assessment developed by the instructor and researcher who developed the lectures. The items were derived directly from the concepts covered in the modules.

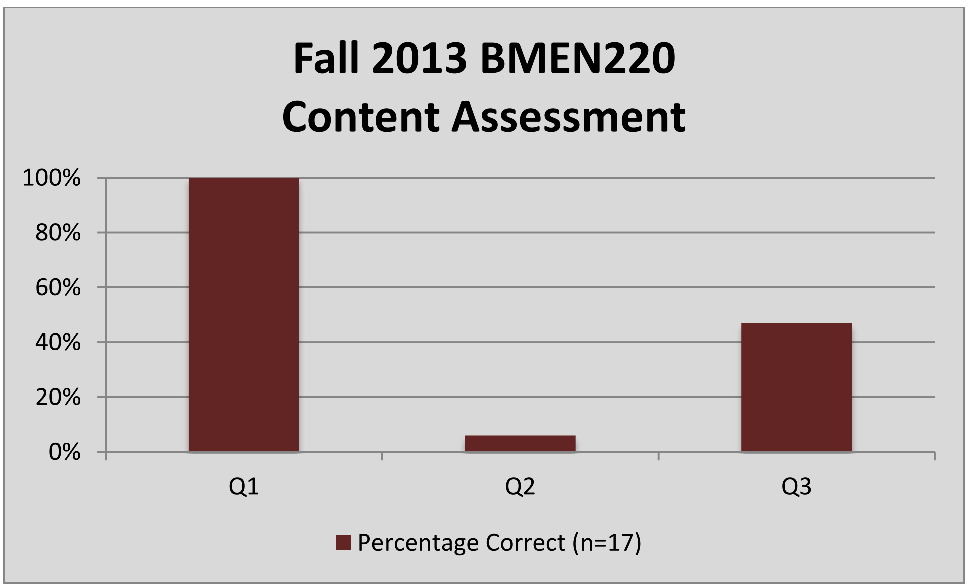
The three content assessment items for BMEN 210 are shown below as well as the results indicating percentage of students who answered each item correctly.

1) Nanotechnology allows researchers to work on a sub-cellular level. (True/False)

2) Name one application of nanotechnology in biomedical engineering. (Short Answer)

3) Which one of the following has nanoscale dimensions: a) muscle, b) nephron, c) ribosome




The content assessment items for BMEN310 are shown below.

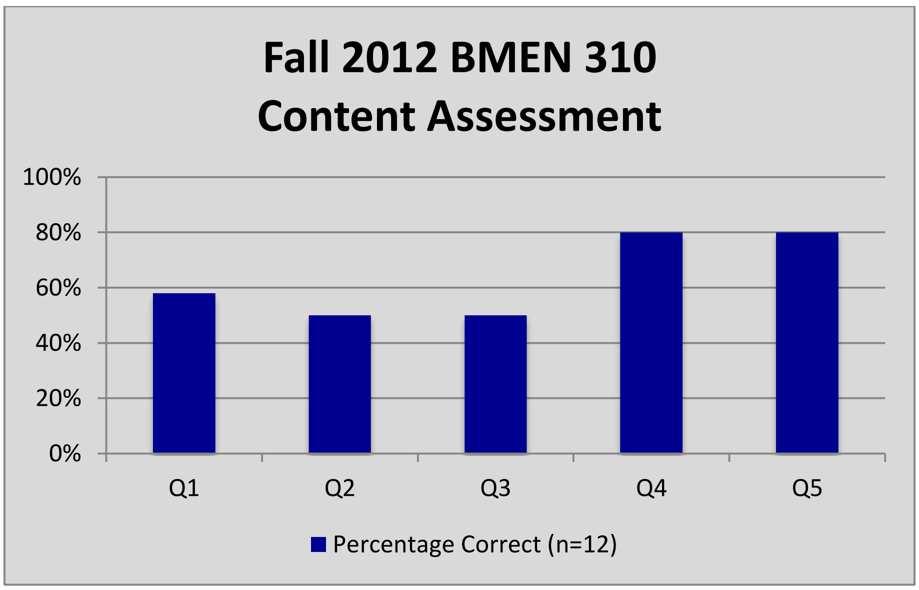
1) A nanometer (nm) means 10^___ of a meter. Nanotechnology refers to devices in which some essential elements have sizes from ---------- nm to thousands of nm. (Fill in the Blanks)

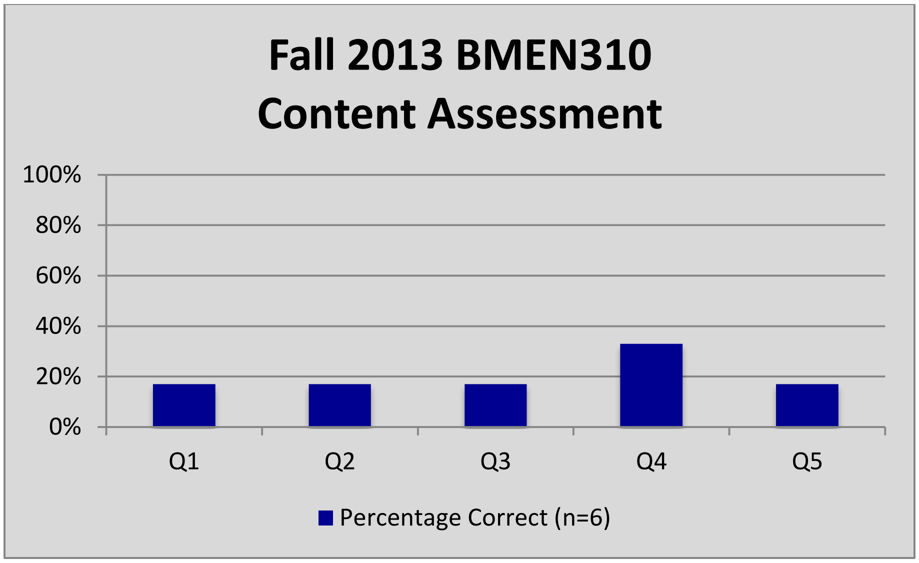
2) The correct nanometer size scale in increasing order (smallest to largest) in terms of well known species is? (a) DNA, virus, proteins, bacteria; (b) Proteins, DNA, virus, bacteria; (c) bacteria, virus, proteins, DNA; (d) DNA, proteins, virus, bacteria

3) Collagen is a major extra cellular matrix protein found in tissues. Self assembly of the collagen molecule results collagen fibrils with size of ….. to ….. nm. Aggregation of collagen fibrils to form a collagen fibrous bundle results in the size of ..... to .....um. (Fill in the Blanks)

4) In polymeric micelle particles hydrophobic polymer blocks form ….. of particle and hydrophilic polymer blocks form ….. of particles. (Fill in the Blanks)

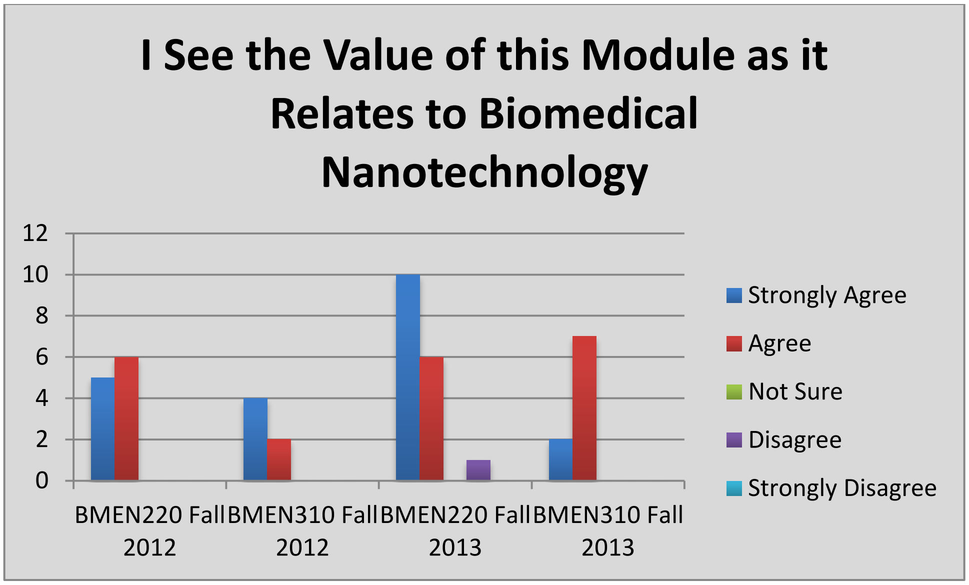
5) When you analyze hierarchical organization of a cortical bone over different length scales, these components of bone you will find in nanometer scale; (a)______, and (b)______. (Fill in the Blanks)

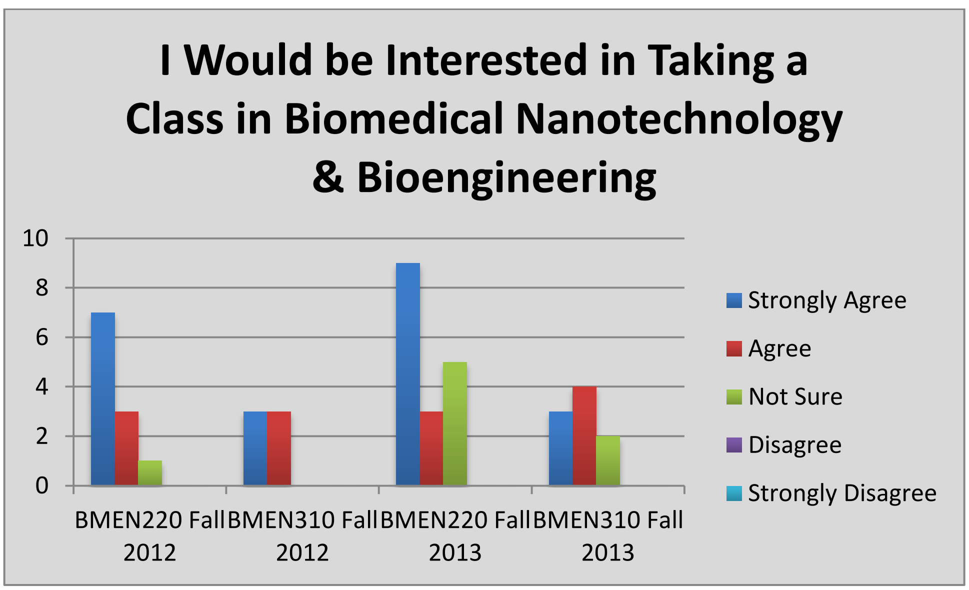





Results from the content assessments demonstrate inconsistency between the two cohorts of students participating in the modules in each class. Overall, the first cohorts of students (Fall 2012) were more successful on the modules than the second cohorts (Fall 2013) respectively. Uneven sample sizes of participants being exposed to these models could be at least partially responsible for some of this variance. There was no change in the modules or the content assessment items between the first and second administrations so individual student variance and cohort effects could also explain some of the variance observed.

In addition to content assessments, student satisfaction was assessed with a 13-question survey using a 5-point Likert scale. Responses ranging from strongly agree to strongly disagree were measured on these dimensions. Overall, respondents indicated value in the modules and an interest in the field of biomedical nanotechnology and the content of the modules. More importantly, students indicated that they would be interested in participating in a course in biomedical technology and nanoengineering.




Although student success on the content modules was varied depending on cohort, all students voiced satisfaction with content and a desire to further their understanding of this area. Their desire to continue studies in this area is consistent with the desired outcome of this phase of the project

## II. Development of team-based biomedical nanotechnology course for undergraduates (Bio-Nano-II)

We developed a team-based special topics course as a technical elective in the Chemical, Biological and Bioengineering Department and this course was offered to all majors who met the prerequisites *(*sophomore to higher level standing with one semester of introductory biology and chemistry or consent of course instructor/coordinator). This course was offered as a special topics course from the bioengineering program BMEN 570 for the last two years and it is in the process of institutionalization as a regular course. This course aims to provide students that have come from differing academic backgrounds, including bioengineering, material science, mechanical engineering and life science, with a detailed understanding of the application of nanotechnology with an emphasis on biomedical technology through classroom lectures and laboratory experiences. Such a semester-long is expected to enhance undergraduate student's fundamental understanding of how the physical and chemical properties of engineered nanomaterials influence their interactions with biological systems. One of the focus areas in this course was nanoparticle-based probe engineering [11], techniques for characterization of nanomaterials; separation sciences; and applications of nanotechnology in biological detection, sensing, imaging and tissue regeneration *(Please see major course topics in Table 2)*. Relevant nanomaterial systems for applications such as iron oxide and gold-based nanoparticles and electrospun nanofibers were presented in lectures and laboratory experiences. This course utilized important findings of previous and several ongoing biomedical nanotechnology-related projects as course materials; for example, we incorporated current experimental results to show why bioconjugation, purifications and dispersion of nanoparticles in body fluids are so critical for the development of a clinical grade nanoparticles system for the detection and treatment of disease like cancers. In addition, the laboratory part of the course allowed the students to perform experiments in order to gain a better understanding of information presented in class and more respect for the amount of work and attention to detail needed to produce advanced, publishable results for peer-reviewed publications.

Similarly, students gain a better understanding of class content and real research if techniques presented in class are reinforced in a lab. For example, nanoprobes were first discussed in class, which was followed by a lab experiment to show the actual nanoparticles. We also used microstructural pictures of our samples created during lab experiments to illustrate the advanced level of research in which their professors and peers are engaged. This motivated the students to learn about advanced techniques for characterization of nanoparticles such as atomic force microscopy (AFM), transmission electron microscopy (TEM), scanning transmission electron microscopy (STEM), and Zetasizer.

Table 2. Major course topics of BMEN 570

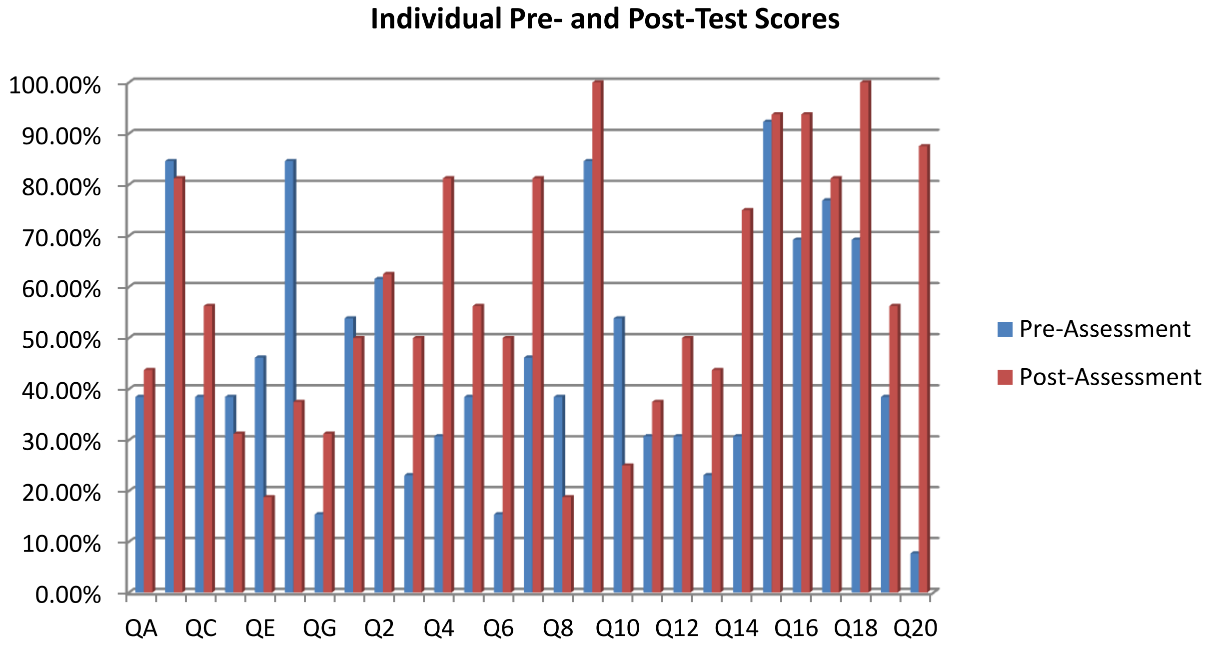
| Course topics | Laboratory |
|---|---|
| Introduction to nanotechnology and biomedical engineering | Iron oxide and gold nanoparticles |
| Nanoparticles (Introduction, synthesis, purification, fictionalization & purification) | Nanoparticle characterization |
| Characterization techniques (SEM, TEM, AFM, fluorescent microscopy, Magnetic properties) | Nanoparticle stability in simulated body fluid, serum, tissue culture medium |
| Biomedical application nanoparticles (Drug delivery, Imaging and diagnostics) | Quantum dots/gold particles |
| Nanofibers (Electrospun fibers, self assembled fibers, Bio-conjugation) | Electrospinning of biopolymers/tissue scaffolds |
| Biomedical application (Tissue regeneration & delivery advantages and issues) | Characterization of nanofibers/tissue engineering scaffolds |
| Titanium nitride nanowires | Pulsed Lesser Deposition (PLD) |
| Carbon nanotube (CN) (Advances of CN & biosensors, conjugation methods & Bio-NEMS) | CN handling, conjugation and cell culture |

| | |
|---|---|
| Ethical and environmental implications of biomedical nanotechnology | ------- |

Assessment and outcomes:

Student learning was assessed using a pre and post-test content assessment. Students in Spring 2013 were assessed on 20 dimensions related to the course topics. These assessments were given at the beginning and conclusion of the semester. Sample items from these assessments are included below:

The spring 2013 cohort contained 17 students and their results are seen below.

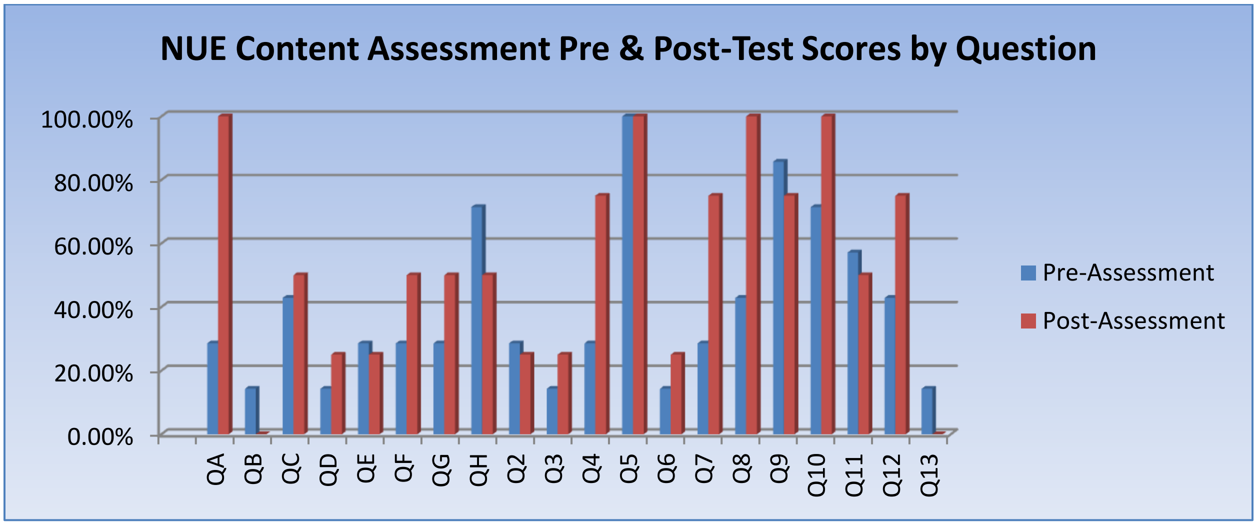



For the second cohort of students (n=4) in Spring 2014, the content assessment was revised to 13 items to better reflect the refined course content. Some of the questions asked in Spring 2013 were removed in second year assessment. Sample items from this assessment are shown below.

2) The correct nanometer size scale in increasing order (smallest to largest) in terms of well known species is:

3) Which nanomanufacturing category to pulsed laser deposition (PLD) and mechanical attrition (MA) fall under?

The results from these assessments for Spring 2014 are shown below.




Overall, students showed improvement in the content dimensions measured from pre to post-test administration. Continued refinement of the testing items and course content will be ongoing. Again, it should be noted that sample sizes between the two courses were uneven.

In addition to the content assessments, students from both BMEN570 courses participated voluntarily in focus groups to gauge student satisfaction in the course. Overall, students responded that their course experiences were positive. Students had many positive things to say about the course, including the positive learning environment that nurtured their learning and growth. Several also commented on their new insight and perspectives on this field and greater insight into this field of study, as it relates to graduate work.

## III. Development of semester-long bio-nanotechnology research-based education (Bio-Nano III)

As a third phase in this NUE project, a semester long research experience class related to biomedical nanotechnology for a limited number of undergraduates was developed. High-performing undergraduate students from activity I and II were recruited to engage in semester-long research projects. Students  received “Independent Study” or “Independent Research” course credit for this systematically mentored by NUE PIs and their graduate students. This course was offered as BMEN 570: Research Experience in Biomedical Nanotechnology and Engineering for CBBE students and MEEN 585: Special Topics for ME students.

In the Fall 2013 and Fall 2014 semesters, 10 students enrolled in the research-based class and completed instructor-supervised research projects. The research projects that students worked on were: “Chitosan-based Nano-Composite Scaffolds for Bone Tissue Engineering”, “Inclusion of *Aloe Vera* in Nanofibrous Membrane Spun from Inverse Emulsion for Guided Tissue Regeneration & Treatment of Periodontitis”, “Fabrication, characterization, and growth mechanism of titanium nitride nanowires”, “Growth and Characterization of Titanium Nitride Nanowires” and “Magnesium Nano Coating on metal”. These projects were presented and evaluated for contents. Supporting documentation including a course syllabus, sample student presentations, and evaluation rubrics were submitted in the NSF-NUE-annual report.

Assessment and outcomes:

Students completed their research projects over the course of the semester and presented their research findings to expert researchers, peer reviewers, and external reviewers. Students also participated in a self-review. Presentations were judged on dimensions ranging from quality of hypothesis to organization of material. Each research project was judged by 9 independent reviewers (including self-review). In addition, student satisfaction was assessed using a student satisfaction survey. Overall, students reported high satisfaction as it relates to course value and a desire to take the course, even if it wasn’t required. Students also voiced increased satisfaction with the opportunity to be innovative and work in the lab on new research topics relevant to the field.

## IV. Interdisciplinary nanoengineering certificate program

As a part of the fourth phase in this NUE project, we are developing an interdisciplinary undergraduate certificate program (INCP) in Interdisciplinary Nanoengineering. The program is envisioned to enhance awareness, instruction, research, understanding of the field and applications in daily life. To earn an interdisciplinary undergraduate certificate in bionano engineering, students need to complete a minimum of 17 credit hours of approved basic science and nanoengineering-related courses including lecture, lab and seminar courses created for the certificate, and have a minimum GPA of 2.5. Some of the existing courses that could be taken by students to receive INCP certificate are listed as follow: (i) CHEM 106 Chemistry (3 hrs), (ii) PHY 251 Calculus Based Physics (3 hrs), (iii) MEEN 360 Materials Science (3 hrs), (iv) MEEN 530 Fundamentals of Nano-science (3 hrs), (v) BMEN 220 Introduction to Biomedical

Engineering (3hrs), (vi) BMEN 310 Biomaterials (3 hrs), (vii) BMEN 325 Bioengineering Lab (2hrs), (viii) BIOL 468 Biol. Tech & Ethics I (3 hrs), (ix) WMI 617 - Environmental Ethics & Philosophy (2 hrs), (x) MEEN 460 Modern Engineering materials (3hrs). A list of new courses that were developed under this NUE project for INCP is as follows: (i) BMEN 570 Bio-Nano (6hrs), and (ii) BMEN/570 Nanoengineering Topics Seminar (1hr).

Since our INCP proposal is in the process of final approval, the students who have completed all the required courses during Spring 2014 were awarded a *Confirmation of Completion Interdisciplinary Bionano Engineering Course Sequence* through the approval by *Department of Chemical, Biological and Bioengineering.*

EDUCATION AND OUTREACH ACTIVITIES

Undergraduate Research Activity:

Under the REU activities carried out under the NUE program, undergraduate students from our home institution were provided opportunities to work on nano-bio related projects during the summer of 2013. Ms. Christina Fenwick (REU) **-** Mechanical Engineering, Senior paired with graduate students working under the supervision of NUE PI. There were 4 undergraduate students being supported by the NUE project. These students worked on a semester-long project related to nanofabrication and devices. Students have been given additional opportunities based on their performances in these courses and their interest in further enhancing their knowledge of bio-nanoengineering.

REV/U and REV/T program activity under NUE:

Supplemental funding was received to pilot an innovative VRS program that complemented the ongoing NSF NUE project at North Carolina A&T State University. The VRS program provided research experience during the academic year as well as the accompanying summer to a veteran undergraduate student (Mr. Chad Chesley-undergraduate in CBBE of NCAT) and a full-time school teacher also with US military veteran status (Mr. Eric Craven- Middle School teacher in the Guilford County System in the State of North Carolina). Chad Chesley (REV/U) worked under the supervision of NUE PI in the development of 3D porous scaffolds for bone tissue application. He also worked closely with graduate students. Mr. Eric Craven (REV/T) with US military veteran status was supported by the NUE supplement grant under the REV/T program. Mr. Craven is a science teacher in a local middle school. He worked with several graduate and undergraduate students at NCAT which enabled him to gain access and exposure to various projects and equipment. He worked on multiple projects related to nanoscience and engineering under the supervision of NUE co-PI.

ACKNOWLEDGEMENT

The authors would like to thank the Engineering Education and Centers (EEC) Division of the US National Science Foundation for providing funding via grant number EEC 1242139 to carry our educational and research activities under Nanotechnology Undergraduate Education (NUE) initiative of the foundation. Authors also acknowledge Veteran Research Supplement VRS Program NSF 13-047 for providing support for REV/U and REV/T.

REFERENCES

1. Nel, A.E., et al., *Understanding biophysicochemical interactions at the nano-bio interface.* Nat Mater, 2009. **8**(7): p. 543-57.
2. Service, R.F., *Nanotechnology takes aim at cancer.* Science, 2005. **310**(5751): p. 1132-1134.
3. Hobson, D.W., *Commercialization of nanotechnology.* Wiley Interdiscip Rev Nanomed Nanobiotechnol, 2009. **1**(2): p. 189-202.
4. Dvir, T., et al., *Nanotechnological strategies for engineering complex tissues.* Nat Nanotechnol. **6**(1): p. 13-22.
5. Chun, Y.W., et al., *Nanostructured bladder tissue replacements.* Wiley Interdisciplinary Reviews-Nanomedicine and Nanobiotechnology, 2011. **3**(2): p. 134-145.
6. Wan, Y.Z., et al., *Preparation and mineralization of three-dimensional carbon nanofibers from bacterial cellulose as potential scaffolds for bone tissue engineering.* Surface & Coatings Technology, 2011. **205**(8-9): p. 2938-2946.
7. Roco, M.C., *Converging science and technology at the nanoscale: opportunities for education and training.* Nat Biotechnol, 2003. **21**(10): p. 1247-9.
8. Sweeney, A.E., P. Vaidyanathan, and S. Seal, *Undergraduate research and education in nanotechnology.* International Journal of Engineering Education, 2006. **22**(1): p. 157-170.
9. Hersam, M.C., M. Luna, and G. Light, *Implementation of interdisciplinary group learning and peer assessment in a nanotechnology engineering course.* Journal of Engineering Education, 2004. **93**(1): p. 49-57.
10. Nanotechnology Long term Impacts and Research Directions: 200-2020, N.R., www.wtec.org/nano2/docs/ChaptersPdf/Ch07_Nanobiosystems_draft_2010-0929_0.pdf.
11. Veiseh, O., et al., *Inhibition of tumor-cell invasion with chlorotoxin-bound superparamagnetic nanoparticles.* Small, 2009. **5**(2): p. 256-64.