AC 2011-1397: DEVELOPING INQUIRY-BASED NANOBIOTECHNOLOGY LABORATORY EXPERIENCE FOR SOPHOMORES

Jianyu Liang, Worcester Polytechnic Institute

Jianyu Liang is Assistant Professor of Materials Science and Engineering. She received her Ph.D. from Brown University in 2005. She joined WPI in September 2004 and has established a Nanomanufacturing and Nanomaterials Laboratory at WPI. Her recent work has focused on developing novel nanomanufacturing approaches, investigating inter-facial properties at nanometer scale, and exploring the applications of nanomaterials in biotechnology, fuel cells and batteries.

Terri A. Camesano, Worcester Polytechnic Institute

Terri A. Camesano is a Professor of Chemical Engineering at Worcester Polytechnic Institute.

©American Society for Engineering Education, 2011

Developing Inquiry-based Nanobiotechnology Laboratory Experience for Sophomores

Abstract:

Nanobiotechnology is a new field that probes the intersection of nanomaterials with biological molecules and cells. Innovations in nanobiotechnology are driving new medical and industrial applications, including targeted drug delivery, clinical diagnostics, imaging, sensing, tissue engineering, and self-assembly of functional materials. While undergraduate students have no doubt heard of the importance of nanotechnology and nanoscience, relatively few can appreciate how the scale of matter affects the fundamental science or behavior of a system. Most learning on this topic tends to occur in upper-level electives or in senior thesis projects or REU programs. Further, our undergraduate curricula do not include enough exploration-based laboratory courses, in which students work towards solving a problem in collaborative teams, rather than following "step-by-step" lab procedures.

This paper discusses the creation at Worcester Polytechnic Institute (WPI) of an inquiry-based series of laboratory modules that are designed to expose students to nanobiotechnology, increase specific skills in nanomaterial synthesis and characterization, augment their interest and confidence in pursuing the subject matter, and encourage them to pursue higher level nano-courses as well as research projects with the support from the NSF CCLI program. Two lab modules, nanopatterned surfaces with relevance for tissue engineering and targeted delivery of therapeutics and creation and evaluation of mechanical properties of nanowires or other nanostructures, are being developed and planned to be offered in Spring 2011 and Spring 2012. This three-credit course will comprise two major sessions:

1. Lecture and conference for learning background, principles and experimental tools and discussing experimental design and lab results;
2. Lab activities for learning and using experimental tools, such as scanning electron microscopy, atomic force microscopy, and nanoparticle synthesis and characterization, to carry out the experimental design.

Sophomores from across engineering and science boundaries are expected to participate in the course, working in multidisciplinary teams wherever possible. Working in teams with mentoring from the faculty, students will gain an exposure and appreciation of important nanotechnology tools. Discussion and communication of research results (oral and written) will be emphasized. Participation will improve specific skills needed to succeed in a career in nanobiotechnology. In addition, students in our class will be actively engaged in the mentoring of the next generation of engineers, by participating in Introduce a Girl to Engineering Day, which is an annual program for middle school girls, held at WPI each February. Qualitative and quantitative evaluation methods will be employed to help us improve and guide the course as it progresses, allow us to determine the impact of the course on students' knowledge, skills, and attitudes and help us ascertain how well we met our goals and objectives.

1. Introduction

Recent years have seen a growing interest in the transformation of engineering undergraduate education towards a more inquiry-based and active approach[1]. Many of the topics our students need to learn are also changing, and there is a recognition that nanotechnology and nanobiotechnology should be included in undergraduate engineering programs. This topical

change comes from a societal need. For example, the miniaturization of biological diagnostics and delivery agents requires interdisciplinary knowledge from mechanical engineering, materials science, chemical engineering, bioengineering, physics, and electrical engineering.

Although our students have no doubt heard about nanotechnology, they currently do not have many opportunities to learn about techniques such as atomic force microscopy (AFM), scanning electron microscopy (SEM), or preparation of nanoparticles in the current curricula. In order to be prepared for careers or graduate programs in the field of nanobiotechnology, there are certain skills that engineering students must have the chance to learn during their undergraduate programs, including both technical skills and the ability to communicate. We believe that early-stage undergraduate engineering students (primarily sophomores) can make substantial progress in their learning of nanobiotechnology, if an educational approach is provided that responds to their abilities and to knowledge of how people learn.

The overall goal of the creation of an inquiry-based series of laboratory modules is to give students the opportunity to learn nanobiotechnology through active, problems-based laboratory experiences, focusing on presenting students with a "Grand Challenge" to which they must respond, framed in the form of two adaptable modules. We follow a learner-centered approach, in which students will be presented with appropriate information or factual knowledge that is consistent with their backgrounds and prior experiences[2]. They will be provided with "just-manageable difficulties" in their lab projects, such that they are challenged enough to stay engaged, but not so challenged that they become discouraged. Failure or making mistakes is an important component of any learning process[3], thus students will be encouraged to take risks in developing solutions to their projects, and we can use any "failures" as learning opportunities. Our philosophy also incorporates elements of the knowledge-centered approach, in which students work collaboratively in groups to formulate questions, construct and test hypotheses, analyze and interpret data, and share results[4,5].

Our course exposes students to research methodology, experimental skills, and the preparation of oral and written laboratory reports, as well as stimulates students' interest in nanobiotechnology, to better prepare them for the changing job market. These goals will be accomplished by providing them with hands-on exposure through laboratory modules that foster creative thinking in a collaborative, problem-based learning environment. The "Grand Challenges" modules each have an inquiry-based design that will be executed by the students in collaborative teams. An evaluation procedure will be used to measure whether their skills and knowledge increases. The objectives of this work are to:

1. Create a new course in nanobiotechnology
2. Increase students' knowledge of nanobiotechnology
3. Increase the skills of undergraduate engineering students in developing research methodology
4. Prepare students to deliver high quality oral and written project presentations
5. Enhance the interest and enthusiasm of undergraduate students for nanobiotechnology
6. Disseminate nanobiotechnology modules to colleagues in a range of engineering departments at other institutions.

Two lab modules, nanopatterned surfaces with relevance for tissue engineering and targeted delivery of therapeutics and creation and evaluation of mechanical properties of nanowires or other nanostructures, are being developed and planned to be offered in Spring 2011 and Spring 2012. WPI does not currently offer any laboratory course in nanotechnology or nanobiotechnology, so this course fills an unmet need for us. Our primary target is sophomore engineering students, particularly from Chemical, Mechanical, and Biomedical Engineering, but since WPI has a flexible six-course requirement in science or engineering (for all majors), we may attract students from other departments to take this course. For Spring 2011, currently 12 students from Chemical, Mechanical, and Biomedical Engineering departments have registered for this class.

1.1 Active, Problem-Based Learning, and a "Grand Challenge" Approach

Studies have widely documented that inquiry-based learning and problem-based learning approaches promote learning and retention, along with development of science process skills[Error! Reference source not found., 6, 7]. Studies in science education since the 1970s report that hands-on, activity-based laboratory instruction that makes science more exciting has a positive influence on students' attitude and achievement in science[8]. Even though the NSF and other agencies and committees have recommended that students be exposed to inquiry-based learning in the earliest stages of their education[9, 10], its practice has been somewhat limited in traditional engineering programs, and often appears more in upper level courses.

The basic premise of our approach is that we want to use the concept of presenting students with a "Grand Challenge" to focus student learning on the acquisition of skills, knowledge, and attitudes, in addition to specific facts. Students will acquire these attributes through an engaged and active approach to learning. The professor is not merely transmitting knowledge to the student, but he or she is engaged in a dialogue with the students in order to help them discover knowledge through a guided mentoring approach[10]. There is reciprocity to the relationship, such that the students' questions and observation also teach the professor, rather than a one-way transfer of facts from professor to student. When students learn with understanding, they can then apply this knowledge to new situations[2]. On the other hand, research has shown that in traditional cookbook-style laboratories, where students follow step-by-step instructions and collect data, the fundamental concern of many students is completion of the task, rather than developing broader understanding or problem-solving skills[11]. Furthermore, they see the scientific process as steps toward anticipated "right answers" rather than as a method for solving a problem or answering a question[12]. They learn to focus on the facts of science rather than the questions that lead to the discovery of those facts[13]. Inquiry-based learning approaches, which emphasize active and student-centered learning, require the learners to actively construct their own meanings that are consistent with their prior ideas rather that passively acquire knowledge transmitted to them. The learning outcomes are the interactive result of the information encountered with the guidance from the instructor, and how the student processes the information[14].

1.2 Need for a Nanobiotechnology Laboratory Experience

To truly understand nanoscience, students not only need textbook explanations, but first-hand experiences in the laboratory. Despite WPI's commitment and the progress already made, none of our current laboratory-based courses encompass nanobiotechnology. We also have very few

laboratory courses in which the students are presented with a "Grand Challenge", and asked to work towards a solution in a collaborative setting, rather than having pre-set experiments for students to perform.

Both "nano" and "bio" opportunities are going to be increasingly available for our students. Nationwide, employment of biological and medical scientists is expected to increase by 10-20% by 2014[15]. Dr. Roco, Senior Advisor for Nanotechnology at NSF, projects that the worldwide workforce necessary to support nanotechnology will be 3 million by 2015[16]. Considering the potential benefits, there is a strong societal need to increase the educated workforce to support nanobiotechnology. We believe that knowledge of nanobiotechnology and skills in specific areas (i.e. nanomaterials characterization, design of experiments, communication of results; these are defined specifically when modules are introduced below) will better prepare our students for jobs that necessitate the combination of biotechnology with nanotechnology and engineering. Our course can help prepare students for these opportunities.

2. Overview of Development of "Grand Challenge" Laboratory Modules

We are developing two "Grand Challenge" laboratory modules for a new Nanobiotechnology Experiential Course targeting sophomore engineering students. The Nanobiotechnology Laboratory Experience will be a beginning course in understanding the properties of nanostructures and in the selection of nanomaterials for biotechnology applications. Fulfilling our objective to create a new course, our student learning outcomes include:

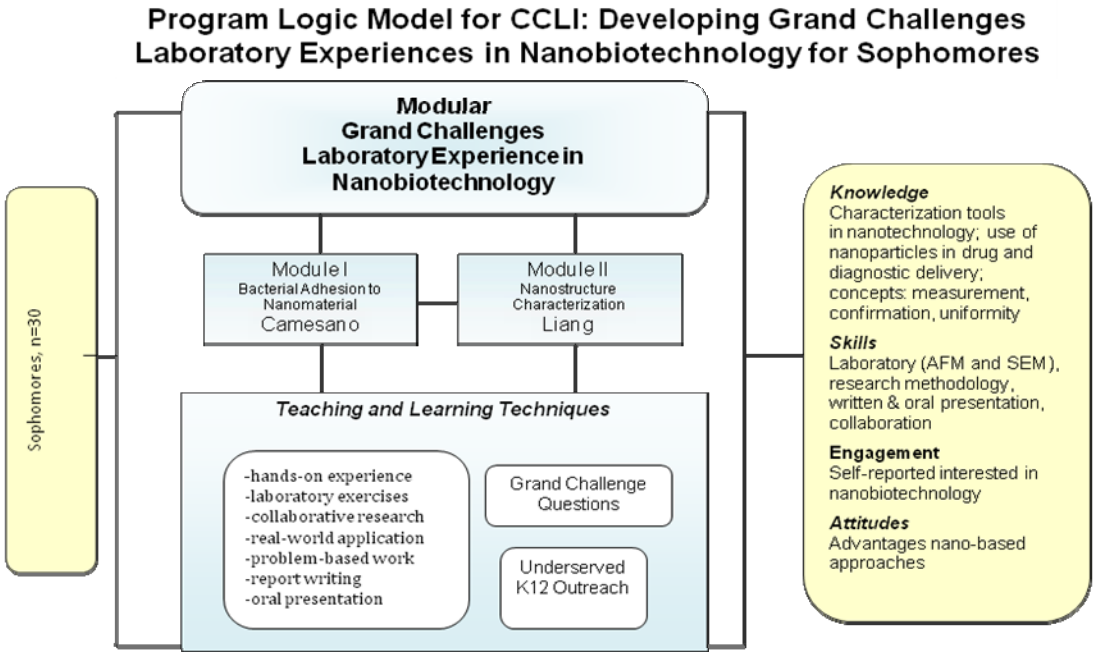
1. Students will have the ability to prepare and characterize nanomaterials, and be exposed to techniques including scanning electron microscopy and atomic force microscopy; students will measure and test mechanical properties of nanomaterials, and to investigate interactions of biological cells with nanomaterials.
2. Students will be able to define a research problem, design appropriate experiments to answer a research question, conduct experiments in the laboratory, and analyze results.
3. Students will be able to explain the concepts of the Grand Challenges modules through high quality oral and written project presentations. Students will be able to articulate their objective, methodology, results, and analyses using attractive slides and exhibiting clear speech.
4. Students will rate their interest in nanobiotechnology more highly on the post-survey than at the beginning of the course.
5. Some students will pursue advanced coursework and research opportunities in these fields (our goal is >75%).

We will achieve these outcomes through our Grand Challenges Modules: **I. Nanopatterned antibacterial surfaces, and II. Creation and characterization of nanostructures for use in bioimplants.** An overview of the course is shown in Figure 1**.**

We selected the topics of these modules based on certain criteria. For example, students must be able to personalize the task and grasp societal relevance. This is particularly important for attracting female and minority students, because research has shown that focusing on the altruistic nature of engineering is an effective way to engage females and minorities. We also require that the module topic poses a challenging multi-variable problem for the learner to solve experimentally, and which will allows learners to work in teams with appropriate faculty guidance. Finally, the module topic should be multidisciplinary, and should enable students to

spend time on one scientific concept and learn several biology and nanotechnology laboratory techniques in one unit.

Figure 1. Overview of Course



Our course will be developed to accommodate a number of different learning styles, following the recommendations of Felder and Silverman[1]. This research suggests that an effective method for learning should involve both active components (i.e., letting students do something in the lab or participate in a discussion), along with a reflective component, which allows the students to analyze or process their observations. They have found that active learners do not learn well in lecture-style or passive settings, and that reflective learners need to be given an opportunity to think about information and develop their own understandings. Another difference in learning styles relates to the order in which students process information, such as sequential or global. For example, while some students are able to learn slowly and steadily as information is presented, master it, and move on (sequential), others may appear lost for some time until a jump in knowledge occurs, allowing things to click into place (global). Since any undergraduate class will be a mix of learning styles, it is helpful to present materials in different ways. Some of the key recommendations from Felder and Silverman's research[1] that we will incorporate into our course are:

- Motivate learning by connecting the topic of the course to previous experiences and learning, as well as future applications
- Present material in different ways (written prose, spoken information, pictures, graphs, videos, computer exercises). In our case, we will illustrate the Grand Challenges in as many methods as possible.

- Allow students time to reflect by pausing at key points during a discussion
- Allow students opportunities to work in teams and learn from one another
- Provide open-ended problems that allow for analysis and synthesis

A consideration we have is that students need to be given a chance to learn about their laboratory module topic, as well as learn about the experimental techniques, as they are going through the course. We cannot "teach" them everything about nanoparticles and scanning electron microscopy in week 1, and then just expect them to apply this in subsequent weeks. In other words, we expect to provide information and opportunities for discussion continuously throughout the course, allowing them to experience trials and failures in the lab, then returning to discussions with the professors, as well as their books and literature, in order to revise and improve their approach. We will provide the Grand Challenges using an existing instructional model, in order to satisfy the above recommendations.

3. 5-E Instructional Model: Engage, Explore, Explain, Elaborate, and Evaluate

One way that we can implement the recommendations of Felder and Silverman is to use the 5-E Instructional Model, which asks students to Engage, Explore, Explain, Elaborate, and Evaluate[17] (Figure 2).

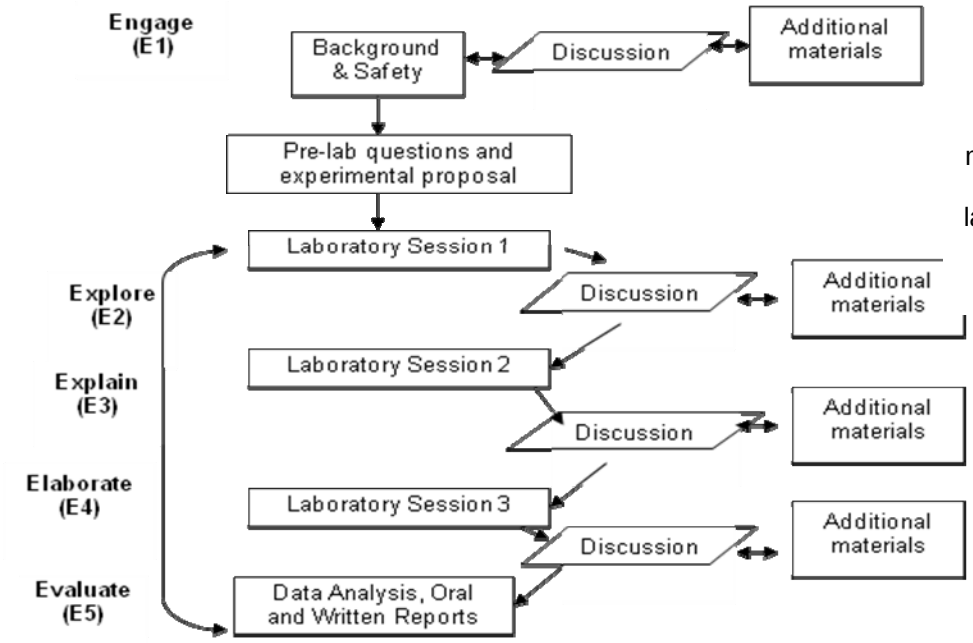


Figure 2. Schematic of 5E Instructional model that we will apply in laboratory course.

The specific application of the 5E Instructional Model to our modules is discussed below.

Module I . Grand challenge: Can you prevent bacterial contamination of a biomaterial by controlling surface morphology at the nanoscale?

During the **Engage** phase, we start with a discussion with the students to help them understand the importance of using nanopatterned surfaces that resist bacterial colonization. Reading materials and links to websites with animations are also provided. The background of this problem is that when a biomaterial is implanted into the body (i.e. catheter, orthopedic

implant, contact lens), a "race for the surface" will ensue, in which the body's own tissue, organ, and blood cells compete with serum proteins and bacteria for attachment sites on the implant[18]. The ultimate goal is to have the implant well-integrated with the body's cells, such as osteoblasts for an orthopedic implant. Nanostructured surfaces can be put to beneficial use for such applications[19]. For example, the use of nanostructured materials including carbon fibers, ceramics, polymers, metals, and composites has helped surgeons realize better bonding between orthopedic implants and bone[20]. In addition to integration with surrounding tissue, surgeons are very concerned with the possibility of nosocomial (hospital acquired) infections developing, which occur when bacteria from the patient's own skin or from the hospital environment accidentally contaminates the implant. These bacteria can quickly form a community environment known as a biofilm, which can be very difficult to treat with conventional antibiotics and often will necessitate removal of the implanted device[21].

Students will be told that their goal is to design and create a submicron-structure surface for minimizing bacterial attachment and promoting tissue integration. Through a discussion with their group members, they will formulate a pre-laboratory proposal describing experiments they could do to address this challenge.

Next, in the **Explore** phase, students will receive feedback from the Faculty and TA about their proposal, and they will be allowed to go into the laboratory to perform experiments. For this module, their experiments will involve using sol-gel methods to coat the surfaces with nanoparticles or nanograins. Next, they will need to characterize their surface roughness by either SEM or AFM with assistance from the TA and our lab manager. They should have proposed a method to test whether bacteria attach to the surface, and to quantify this attachment. We will try to guide them towards using fluorescence or phase contract microscopy, but some groups may wish to propose other ideas. As long as they involve common equipment that we have in one of the laboratories, we can let them try other solutions to quantify surface roughness and bacterial attachment. This will likely not occur all in one lab session.

In the **Explain** phase, the lab groups will come together and each group will have a chance to briefly present their lab results to the class. After learning from one another, students will **Elaborate** on their experimental plan, and return to the lab for a second **Explore** phase in which they can conduct additional experiments or fix problems they had in the first session.

Finally, students will come to the **Evaluation phase**, where they will prepare a conference-format oral presentation. They will also be asked to raise post-laboratory questions that have arisen from their lab observations, and explain how they would conduct experiments to address these remaining questions.

The outcomes of this Module are that students will:
…procure an SEM image showing micro- and/or nanofeatures
…determine surface roughness
…compare SEM and AFM images
…distinguish between the advantages and limitations of SEM and AFM images
…design a plan to quantify the number of bacteria attached to samples
…compare their lab data with data from the literature

Experimental Details

Lab session one, Challenge: How to create a submicron surface pattern that can lead to desired minimization of bacterial attachment?

Students will be introduced to the sol-gel process to create sub-micron size surface features. Sol-gel technique is a simple method widely used to prepared ceramic and metal nanoparticles on various substrates. The process only involves conventional chemistry or biochemistry laboratory procedures such as mixing, dipping, and calcinations and can be performed in our undergraduate teaching labs. Dr. Liang's group has extensive experience in using sol-gel method to fabricate nanocrystalline Al_2O_3, TiO_2, SiO_2, and ZrO_2 thin films[22]. By adjusting process parameters, such as concentration, acidity, and temperature, the size of nanoparticles can be adjusted. TiO_2 will be the primary nanoparticles in this lab module. Each student team will design a nanocrystalline substrate to work with and justify their decision based on their understanding of bacterial/surface interactions and the limitations of sol-gel method and create such a nanocrystalline substrate. The TA and lab technician will demonstrate the lab procedures and supervise the students' activities to help them make the surface pattern.

Lab session two, Challenge: How do you know what surface structure has been created?

Student will need to image the surfaces. They will be provided with information on microscopes commonly used in materials labs, such as AFM and SEM. Student teams can decide which method will be more desirable for their sample characterization and justify their decision. The advantages of using AFM are that no special sample preparation is required, and extremely high resolution images can be obtained. Sample damage is also minimized since the stiffness of the scanning probe can be optimized for a particular sample. Prof. Camesano has substantial experience in using the AFM in her research program, including on projects that have led to publications by undergraduate authors[23, 24, 25]. Although these projects represented longer-term efforts, we feel comfortable enough adapting our AFM protocol so that undergraduates can gain experience on this important and powerful instrument. The TA will assist them in capturing images of the samples and in minimizing image artifacts that are common for new users.

The SEM provides straightforward visualization of nanomaterials and easy interpretation of results. From our previous experience, students are always very impressed and excited when they get their first SEM image showing micro- and/or nanofeatures. Our SEM Laboratory houses a JEOL JSM-840 SEM equipped with an Energy Dispersive X-ray (EDX) Analyzer, which Prof. Liang uses extensively in her research. The features created by student teams can be conveniently characterized by our SEM without additional surface coating or inducing sample damage. The SEM lab provides training and technician assistance to students and faculty. The TA will assist student teams in capturing images of the samples.

Once images at various magnifications and locations have been acquired, the students will perform off-line analyses to determine the surface roughness and size of any surface features. Based on pooling the class's data, students can compare the SEM and AFM images to help them appreciate the advantages and limitations of each.

Lab session three, Challenge: How to evaluate if the surface is antibacterial?

The students will be provided with *Staphylococcus epidermidis*, a common biofilm-associated bacterium in orthopedic implant infections that does not present an undue safety risk

for students in a supervised laboratory. Student teams will design plans for quantifying the number of bacteria attached to the sub-micropatterned surfaces, using fluorescence microscopy. Students will need to relate bacterial attachment to the properties of the samples they measured in the previous sessions, and to compare with data from the literature.

Module II. Grand challenge: Can you create a material that mimics human bone?

Creation and evaluation of mechanical properties of nanostructures

We will start **engaging** the students by discussing the basic structure of human bone, students personal experience with bone implantation, and the potential societal and economic impact of nanobiotechnology enabled bone substitute materials. Human bone is a natural composite with a complex hierarchical microstructure that can be considered at many dimensional scales[26]. On the microstructure level are the osteons (up to 200–300 μm diameter), which are large hollow fibres composed of concentric lamellae and pores. At the shortest length-scale, it is composed of type-I collagen fibres (up to 15 μm in length, 50–70 nm in diameter) bound and impregnated with carbonated apatite nanocrystals (tens of nm's in length and width, 2–3 nm thick). This specific structure has been associated with the physical properties of bone, such as stiffness, toughness, elasticity, etc.

Medical procedures to address bone-related injury are prevalent in the U.S., with ~900,000 hospitalizations for fractures and >800,000 grafting procedures annually[27, 28, 29]. Polymethylmethacrylate (PMMA) bone cement (BC) has been widely used in orthopedic surgery since its introduction by Charnley in 1960[30]. While clinically successful PMMA BCs still suffer from its unsatisfactory mechanical and exothermic reaction properties. Hydroxyapatite (HA) is another promising bone substitute because of it similarity to the carbonated apatitic calcium phosphate mineral found in human bones and teeth. Although HA has been one of the most used restorative materials for the repair of human hard tissues and is biocompatible, the intrinsic brittleness and poor strength of sintered HA restricts its clinical applications under load-bearing conditions[31, 32]. Recent studies have shown that by integrating HA nanoparticles into the PMMA bone cements, the mechanical property of the bioactive bone cements can be improved[33, 34, 35].

The goal of this lab project is to design a nanocomposite bone substitute material with improved mechanical properties by integrating HA nanoparicles in polymethylmethacrylate (PMMA) bone cement. Through a discussion with their group members, the students will formulate a pre-laboratory proposal describing experiments they could do to address this challenge.

In the **Explore** phase, students will receive feedback from the Faculty and TA about their proposal, and they will be allowed to go into the laboratory to perform experiments. In this module, their experiments will involve forming the nanocomposite bone substitute material, characterize the sample microstructure and morphology by SEM with assistance from the TA and our lab manager, and test a key mechanical property of the material with assistance from the TA. This lab module will consist three lab sessions.

After each lab session, the student groups will come together to **explain** their lab results to the class. After learning from one another, students will **elaborate** on their next experimental

plan, and return to the lab for a second **explore** phase in which they can conduct additional experiments or fix problems they had in the first session.

Finally, in the **evaluation phase**, the students will prepare a conference-format oral presentation. They will be asked to raise post-laboratory questions that have arisen from their lab experience, and explain how they would conduct future experiments to address these remaining questions.

The outcomes of this Module are that students will:
…appraise basic material properties, availability, cost and performance to select HA powder and PMMA bone cement
…obtain SEM images of nanopowders and a nanocomposite material
…identify mechanical testing standards and techniques
…propose a mechanical property to measure
…select a measurement/testing approach
…conduct measurements with assistance
…discuss the impact of different variables in the constructions of nanocomposites

Experimental Details:
Lab session one, Challenge: How do you characterize the size and morphology of the HA powder and PMMA bone cement that form your composite material?
Each student team will specify their choice of HA powder and PMMA bone cement, taking into consideration basic material properties, availability, cost, and performance expectations of the final product. They will decide on a characterization method to study the morphology and the size distribution of their basic materials.
Students will be introduced to basic structure-property relations and characterization techniques, such as X-ray diffraction (XRD) and SEM. HA and PMMA bone cement materials will be purchased by the TA. Student teams will decide on what material property is important for their goals and select a suitable experimental method to obtain the information.

Lab session two, Challenge: How to effectively construct a nanocomposite mimicking human bone and how to confirm the microstructure?
In their experimental proposal, student teams will need to take into consideration variables such as type of bonding and/or filling material, composition of the composite, effective dispersion of HA in the PMMA matrix, calcination conditions, etc. Student teams will synthesize nanocomposite samples with different compositions and feature sizes according to their design, and will select appropriate characterization methods to confirm the microstructure of the formulated composites, such as SEM.

Lab session three, Challenge: How to verify the mechanical properties of the constructed nanocomposite bone substitutes?
Basic mechanical testing standards and techniques will be introduced, such as tensile test, compression test, indentation test, 3-point flexural test, etc. WPI's Materials Science and Engineering Laboratory has equipment for all conventional materials testing and technician support is available to our students. Student teams will propose one key property to measure, select a measurement approach, and do the measurements with assistance.

Students will analyze their data and explain the materials' performance based on their understanding of structure-property relations. Students can discuss the impact of the different variables in the construction of the nanocomposites by analyzing the data from all groups.

4. Encourage the Participation of Females and Underrepresented Minorities in Nanobiotechnology through K-12 Outreach

Exposure to female engineering role models has also been demonstrated to be effective in increasing female participation in engineering[36]. We will follow a pipeline approach and make use of student-to-student mentoring, by asking the undergraduate students from the course to become mentors to middle-school and high school students through a program titled "Introducing a Girl to Engineering Day", which specifically targets females. This program was discontinued in the past two years. Presently, we are initiating the reinstatement of this full-day workshop, in which 60 girls (grades 9-12) and their parents visit campus. Our undergraduates in the course will be encouraged to volunteer as activity leaders for the program. While participation will not be required, we expect that at least 50% of students will volunteer, based on prior experience.

5. Evaluation Plan

The evaluation plan was developed as a collaborative effort of the instructors and Dr. Jeanne Hubelbank, an evaluation consultant. Our evaluation plan is based on collaborative[37] and participatory evaluation models[38], and will combine qualitative and quantitative methods. Formative methods will help us improve and guide the course as it progresses and in the second year. Summative methods allow us to determine the impact of the course on students' knowledge, skills, and attitudes. It will help us ascertain how well we met our goals and objectives.

Evaluation is an integral part of the project. It began with project planning, will continue during the project, and will synthesize all data at the end. The purposes of the evaluation are to monitor and document implementation, to assess students' knowledge, skills, and attitudes, and to determine attainment of project goals and objectives. A series of evaluation questions that are closely tied to program objectives guide the evaluation. Data to answer the questions, methods and tools to gather data, source of data, responsibility for data collection, and a timeline are articulated in an evaluation template that will frame evaluation implementation.

The design of the summative component of the evaluation is one group pre-post outcome. While random selection and comparison groups are stronger designs, they are not viable in a small institution such as WPI. Triangulation of data from multiple methods and input from outside reviewers will help strengthen our design.

Related to the project objectives and evaluation questions, planned measures include pre-post tests of knowledge (e.g., students asked to design experiments that respond to a Grand Challenge question similar to those asked in the course), lab reports, surveys, clicker responses for instant feed-back, minute papers, and focus groups or interviews. Content validity and reliability will be established for knowledge tests. Planned analyses include standard statistical tests such as analysis of covariance and qualitative analysis such as content analysis of open-ended responses.

Formative Evaluation Questions – Implementation, Monitoring and Documentation

Objective: to create a new course in bionanotechnology

…What are students' reactions to the modules? (e.g., access, support, availability, time, instructions, instruction, activities, challenge topics)

…What concepts do students report as clear/confusing?

…What were students' reactions to the course content and learning activities?

…What characteristics of the course facilitated or impeded students' learning?

…To what extent were the criteria for the modules present?

…What is the content of the course? its model of instruction? What learning theories served as a basis for instruction?

…How was the content of the course established?

…What types of learning activities were provided?

…What services, materials, and resources were used and needed?

…How many students enrolled in the course?

…What were the genders of the students?

…What were the students' majors?

…What were students' prior experiences with nanobiotechnology?

… How many faculty members, other than PIs, participated? From which departments?

… To what extent was there collaboration with other faculty members?

… How much time did it take to prepare and teach the course? Compared to similar courses?

… How was the course shared with other faculty at WPI and other institutions?

…How often did the External Advisory Board communicate, and what did the members report?

…To what extent were the External Advisory Board's recommendations acted upon?

… What was the nature and involvement of the outreach to middle school classrooms?

Summative Evaluation Questions Single-Group Pre-Post Outcome Design

Objective: to increase students' knowledge of bionanotechnology

…To what extent did students' scores on knowledge tests increase from pre to post test?

…To what extent where students better able to design an experiment to respond to a Grand Challenge at the end of the course than at the beginning of the course?

…How well were students able to prepare and characterize nanomaterials?

...To what extent did students' oral and written presentations show evidence of strong research methodology, i.e., well-defined research problem, design, conduct, and analysis of experiment (well-defined to be articulated in rubrics or specific criteria)

…To what extent did students explain and employ cleanroom practices?

Objective: enhance the interest and enthusiasm of undergraduate students for nanobioscience and nanobiotechnology

… How many students who take the course enrolled in advanced course work and/or research opportunities in nanobioscience and nanobiotechnology?

… How many students rate their interest in nanobiotechnology higher at the end of the course than at the beginning?

…What percentage of students participated in at least one volunteer middle school outreach activity?

Objective: disseminate nanobiotechnology modules to colleagues in a range of engineering departments at other institutions

…What and how many training videos were developed and on what websites were they posted?

…At what conferences and/or journals were findings presented and/or published or submitted for presentation or publication?

6. Summary

At WPI, we are developing inquiry-based laboratory experience modules that will expose sophomore students to nanopatterned surfaces with relevance for tissue engineering and evaluation of mechanical properties of nanowires or other nanostructures that could be used in implants. Each of these cutting-edge topics addresses applications of national need. Students who complete this course are better prepared to pursue advanced courses and projects, as well as more competitive in the changing industrial world that now embraces nanobiotechnology.

References:

1. Felder, R.M. and L.K. Silverman, *Learning and teaching styles in engineering education.* Engineering Education, 1988 (and preface added in 2002). **78**: p. 674-681.
2. Donovan, M.S. and J.D. Bransford, *Introduction*, in *How Students Learn: History, Mathematics, and Science in the Classroom*, N.R. Council, Editor. 2005, Committee on How People Learn, A Targeted Report for Teachers, Center for Studies on Behavior and Development. p. 1-28.
3. Brown, A.L. and J.C. Campione, *Guided discovery in a community of learners*, in *Classroom Lessons: Integrating Cognitive Theory and Classroom Practices*, K. McGilly, Editor. 1994, MIT Press: Cambridge, MA.
4. Madhuri, M.B., C., *"Do I need to know this for the exam?" Using popular media, inquiry-based laboratories, and a community of scientific practice to motivate students to learn developmental biology.* CBE- Life Sciences Education, 2008. **7**: p. 36-44.
5. *BIO 2010, Transforming undergraduate education for future research biologists*. 2003, Washington, D.C.: National Research Council, National Academies Press.
6. Council, N.R., *BIO 2010, Transforming undergraduate education for future research biologists*. 2003, Washington, D.C.: National Academies Press.
7. Coppola, B.P., *Laboratory instruction: ensuring an active learning experience*, in *McKeachie's Teaching Tips*, W. McKeachie, Editor. 2002, Houghton Mifflin: Boston, MA.
8. Gunsch, L., *A comparison of student's achievement and attitude changes resulting from a laboratory and non-laboratory approach to general education physical science courses*. 1972, University of Northern Colorado.
9. Foundataion, N.S., *Shaping the future: New expectations for undergraduate education in science, mathematics, engineering, and technology, NSF 96-139*. 1996, Arlington, VA: National Science Foundation.
10. *Reinventing Undergraduate Education: A Blueprint for America's Research Universities*. 1998, Stonybrook, NY: The Boyer Commission on Educating Undergraduates in the Research University, The Carnegie Foundation for the Advancement of Teaching.
11. Taraban, R., et al., *Effects of active-learning experiences on achievement, attitudes, and behaviors in high school biology.* Journal of Research in Science Teaching, 2007.
12. DiPasquale, D.M., C.L. Mason, and F.W. Kolkhorst, *Exercise in inquiry.* Journal of College Science Teaching, 2003. **32**: p. 388-393.
13. Polacek, K.M. and E.L. Keeling, *Easy ways to promote inquiry in a laboratory course.* Journal of College Science Teaching, 2005: p. 52-55.

14. Marbach-Ad, G. and P.G. Sokolove, *Can undergraduate biology students learn to ask higher level questions?* Journal of Research in Science Teaching, 2000. **37**: p. 854-870.
15. *U.S. Bureau of Labor Statistics Occupational Outlook Handbook*. 2006-2007.
16. Roco, M.C., *Nanotechnology- a frontier for engineering education.* International Journal of Engineering Education, 2002. **18**: p. 488-497.
17. Bybee, R.W., *Achieving Scientific Literacy*. 1997, Portsmouth, NH: Heinemann.
18. Gristina, A.G., *Biomaterial-centered infection: Microbial adhesion versus tissue integration.* Science, 1987. **237**: p. 1588-1595.
19. Colon, G., B.C. Ward, and T.J. Webster, *Increased osteoblast and decreased Staphylococcus epidermidis functions on nanophase ZnO and TiO2.* Journal of Biomedical Materials Research Part A, 2006. **78A**(3): p. 595-604.
20. Buser, D., et al., *Interface shear strength of titanium implants with sandblasted and acid-etched surface: A biomechanical study in the maxilla of miniature pigs.* Journal of Biomedical Materials Resarch, 1999. **45**: p. 75-83.
21. Khardori, N. and M. Yassien, *Biofilms in device-related infection.* Journal of Industrial Microbiology, 1995. **15**: p. 141-147.
22. Li, Z. and J. Liang. *Preparation of metallic-ceramic composite membranes on 316L porous stainless steel supports via sol-gel technique*. in *2009 IMAPS New England Technical Symposium*. 2008. Boxborough, Massachusetts.
23. Pouliot, J.M., et al., *Adhesion of Aureobasidium pullulans is affected by uronic acid-based polymers and pullulan.* Biomacromolecules, 2005. **6**: p. 1122-1131.
24. Liu, Y., et al., *Investigation of role of cranberry juice on surface characteristics and molecular-scale adhesion behavior of Escherichia coli by atomic force microscopy.* Biotechnology and Bioengineering, 2006. **93**: p. 297-305.
25. Strauss, J., et al., *Retention and viability of Staphylococcus epidermidis on protein-coated self-assembled monolayers*, in *Structure, Interactions and Reactivity at Microbial Interfaces, ACS Symposium Series*, T.A. Camesano and C.M. Mello, Editors. In press, Oxford University Press: New York.
26. Park, J.B. and R.S. Lakes, *Biomaterials: An Introduction*. 1992, New York: Plenum.
27. Langer, R. and J.P. Vacanti, *Tissue engineering.* Science (Washington, DC, United States), 1993. **260**: p. 920-925.
28. Laurencin, C.T., et al., *Tissue engineering: orthopedic applications.* Annual Revew of Biomedical Engineering, 1999.
29. Temenoff, J.S. and A.G. Mikos, *Injectable biodegradable materials for orthopedic tissue engineering.* Biomaterials, 2000. **21**: p. 2405-2412.
30. Charnley, J., *Anchorage of femoral head prosthesis to the shaft of the femur.* Journal of Bone and Joint Surgery, 1960. **42B**(28-30).
31. Durucan, C. and P.W. Brown, *Calcium-deficient hydroxyapatite-PLGA composites: mechanical and microstructural investigation.* Journal of Biomedical Materials Resarch, 2000. **51**: p. 726-734.
32. Durucan, C. and P.W. Brown, *Low temperature formation of calcium-deficient hydroxyapatite-PLA/PLGA composites.* Journal of Biomedical Materials Resarch, 2000. **51**: p. 717-725.
33. Wang, C.X. and J. Tong, *Interfacial strength of novel PMMA/HA/nanoclay bone cement.* BIomedical Materials Engineering, 2008. **18**: p. 367-375.
34. Moursi, A.M., et al., *Enhanced osteoblast response to a polymethacrylate2hem.oxyapatite composite.* Biomaterials, 2002. **23**: p. 133-144.
35. Harper, E.J., J.C. Behiri, and W. Bonfield, *Flexural and fatigue properties of a bone cement based on polyethylmethacrylate and hydroxyapatite.* Journal of Materials Science and Materials in Medicine, 1995. **12**: p. 799-803.
36. Sontgerath, S., et al. *Who teaches matters- providing female role models and gender inclusive curricula for middle school students*. in *WEPAN*. 2004. Albuquerque, NM.
37. Patton, M.Q., *Utilization Focused Evaluation: The New Century Text*. Vol. 3rd edition. 1997, Thousand Oaks, CA: Sage.
38. Cousins, J.B. and E. Whitmore, *Framing Participatory Evaluation.* New Directions in Evaluation, 1998. **80**: p. 5-23.