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Practical Aspects of Creating an Interdisciplinary Nanotechnology Laboratory Course for Freshmen

Kurt Winkelmann

Department of Chemistry, Florida Institute of Technology, Melbourne, Florida 32901, USA

The Florida Institute of Technology offers a unique *Nanoscience and Nanotechnology* laboratory course exclusively for first-year undergraduate students. Laboratory experiments are team-taught by chemistry, physics, and chemical engineering faculty. During weekly three-hour laboratory sessions, students synthesize nanomaterials and obtain hands-on experience characterizing samples with scanning probe microscopes. Surveys of former students indicate that the course provides significant educational benefits, such as motivating them to pursue undergraduate research and co-op positions. Based on the author's experience, this paper provides guidance for designing such a course. Topics include the course's structure, laboratory activities, student feedback, and the benefits and challenges of teaching such a laboratory course to first-year undergraduate students.

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RESEARCH ARTICLE

1. INTRODUCTION

In 2004, the Florida Institute of Technology (Florida Tech) began offering a *Nanoscience and Nanotechnology* (NSNT) laboratory course that is unusual in several ways: (1) the course is offered exclusively to first-year undergraduate students majoring in any field of science or engineering, (2) each student operates a scanning tunneling microscope (STM) and atomic force microscope (AFM), and (3) the course is team-taught by three faculty members from the departments of chemistry, chemical engineering, and physics. While introductory undergraduate level nanotechnology courses are becoming more common, a review of college curricula in the United States and other countries shows that these three characteristics provide Florida Tech's students with a unique learning experience. Its primary goal is to introduce students to a wide range of topics that reflect the diversity of the nanotechnology field. The course instructors hoped that it would encourage NSNT students to continue their studies of science and engineering in subsequent upper-level courses and through undergraduate research. Each of the three major aspects of the NSNT course and the achievement of these course goals are discussed in detail.

2. NANOTECHNOLOGY FOR FRESHMEN

Nanotechnology is most often taught in upper-level courses to students who can understand quantum mechanics and perform experiments using advanced instrumentation. While such courses are certainly valuable, freshmen are still capable of learning the basics of nanotechnology using knowledge gained from the first semester of general chemistry. Relatively simple laboratory experiments can illustrate fundamental aspects of nanotechnology. Teaching nanotechnology to freshmen creates some challenges for the instructors but there are also educational benefits to introducing this subject to freshmen.

The only prerequisite for Florida Tech's NSNT course is one semester of general chemistry lecture and laboratory. The second semester of general chemistry is useful since it reinforces important knowledge and laboratory skills, but is considered optional. All freshman science and engineering students enroll in one semester of general chemistry, but most engineers are not required to take two semesters of general chemistry. Students completing one semester of general chemistry have learned the relevant background theory, practiced their laboratory skills, and possess basic skills common to scientists and engineers. Table I lists concepts that are usually covered during the first semester of general chemistry and that are related to nanoscience and technology. Nanoscience and nanotechnology laboratory activities that require applications of those concepts are provided in Table II. The author has found that general chemistry textbooks provide adequate coverage of these topics and NSNT students are advised to review the relevant general chemistry background information prior to the laboratory session. Selection of other "essential" topics depends somewhat upon the instructors' choice of experiments.

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Table I. General chemistry topics essential to successful completion of NSNT laboratory activities, presented in order of appearance in many general chemistry textbooks.

Topic	Topic is an essential aspect of understanding…
Dimensional analysis (unit conversion), metric units	Analyzing data from all experiments
Atomic theory (Dalton's law, structure of the atom, etc.)	All topics related to nanotechnology related to synthesis and characterization
Stoichiometry	Nanoparticle synthesis
Oxidation–reduction reactions	Synthesis of metal nanoparticles and carbon nanotubes
Wave/frequency/energy of light	Absorbance spectroscopy
Quantized energy levels	Absorbance of light by nanoparticles
Bonding, Lewis structures	Synthesis of ionic nanoparticles, hybridization of carbon in carbon nanotubes, STM image features
Intermolecular forces	Properties of nanoparticles in aqueous solutions, synthesis of nanoparticles, structure of colloids

Students' lack of prior knowledge about nanotechnology does not present as difficult of a challenge as it may first appear. Instructors obviously teach a simplified version of the full quantum theory, but the assigned readings and prelaboratory lectures provide enough guidance for students to perform the procedure and understand their results. Useful explanations of nanoscale phenomena that are appropriate for freshmen have been published in the literature (Campbell et al., 1999; Campbell, Freidinger, Hastings, & Querns, 2002; Campbell et al., 2008; Sohlberg, 2006). These references provide instructors with some "best practices" for conveying complicated chemical and quantum mechanics theory to undergraduates. The instructors have learned not to overwhelm students with background information and they try to remember that they are teaching an introductory course. A similar pre-requisite has been used successfully in an introductory nanotechnology lecture class also (Porter, 2007, 2008).

The following example shows how an instructor can simplify a complicated quantum mechanics topic for freshmen. Synthesis of nanoparticles is a useful experiment to demonstrate some differences between nanoscale and bulk materials. The most striking change is that the color of nanoparticles can vary depending on the particle size. Bulk cadmium sulfide (CdS) is orange, while nanosized CdS is yellow. This phenomenon is explained to freshmen in a handout given during the previous week's laboratory activity and then during the prelab lecture. First, students are reminded of concepts they learned in general chemistry:

(1) the relationship between light's color, energy, wavelength and frequency,

(2) the color of an object depends on the colors of light reflected, and

(3) the energy levels in atoms and molecules are quantized.

The dependence of the CdS color on particle size is related to the energy difference (the band gap) between the material's ground state (valence band) and excited state (conduction band). These are presented as another example of quantized energy levels, although in this case the energy levels are a property of unit cells within a crystal and not just an isolated molecule. Bands form because each CdS unit cell has its own ground and excited states, which have slightly different energies compared to the ground and excited states of all the other CdS unit cells within the crystal. A large group of very closely spaced ground state energy levels form a band, and an analogous band is formed from the excited states. The instructor illustrates this on a dry erase board by drawing many pairs of energy levels, depicted as closely spaced horizontal lines, to form the bands. As more lines are added, indicating more CdS unit cells within the crystal, the space between

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Table II. Laboratory activities for the Florida Tech NSNT class.

Week	Description of activity	Reference
1	Synthesis of sol–gel for templated carbon foams	Han & Hyeon, 1999
2	Preparing metallic thin films	
3	Lecture and demonstration of STM and AFM	
4	Preparing STM tips	Ibe et al., 1990
5	Imaging samples with STM and AFM (group A)	
6	Imaging samples with STM and AFM (group B)	
7	Synthesizing and study of ferrofluids	Berger et al., 1999
8	Preparing catalyst for carbon nanotube synthesis	Anderson & Rodriguez, 1999; Chambers, Park, Baker, & Rodriguez, 1998; Fahlman, 2002
9	Imaging carbon nanotubes with TEM	
10	Synthesizing Au nanoparticles	McFarland, Haynes, Mirkin, Van Duyne, & Godwin, 2004
11	Synthesizing CdS nanoparticles	Winkelmann, Noviello, & Brooks, 2007
12	Guest seminars	
13	Tour of research laboratories	
14	Oral presentations	

the bands decreases. This illustrates that the energy difference between the valence and conduction bands decreases as the particle size increases. On the board, the distance between the bottom-most line in the conduction band and the top-most line in the valence band decreases. Returning to the relationship between energy and wavelength of light, students see that the wavelength light that can be absorbed by the CdS particle increases as the energy difference between the bands decreases. This simple explanation of band theory is built entirely upon information found in the quantum mechanics chapter of any general chemistry textbook.

Proper laboratory skills are equally important. By completing general chemistry laboratory requirements, students know how to use common pieces of labware and know how to perform tasks properly and safely, such as decanting solutions to separate a solid from a solution, handling hot liquids, and dispensing chemicals. In some cases, the NSNT laboratory activity involves a procedure that is new to students, and so the instructor must demonstrate the technique. Even here, the students' prior experience in general chemistry laboratory helps them to pay attention and follow directions provided in the instructor's pre-lab lecture and the printed experimental procedure. Laboratory safety, in terms of both the well-being of the students and compliance with environmental regulations, is a primary concern for the instructors. Having completed one semester of general chemistry laboratory already, the NSNT students already know how to behave in the laboratory safely and can properly dispose of hazardous chemicals.

A third group of necessary skills is basic understanding of common scientific tools of analysis. Students should be comfortable performing simple mathematics (arithmetic and algebra, not trigonometry and calculus) and using a personal computer. They must be able to interpret a graph and make approximate predictions based on trends in the data and their observations. Recording their observations and data, and writing a laboratory report may also be required, depending on how the instructor wishes to grade the students. In the case of Florida Tech's NSNT course, the students write a report and give a short presentation to the class. Students practice writing and library research skills in their freshman English courses. Since students may not have much experience presenting technical information to a class, the instructors give them some leeway when grading the students' public speaking skills and instead focus on the content and organization of the presentation.

Based on the author's experience with teaching the introductory nanotechnology laboratory course for freshmen for four years, students need a minimum of one semester of college that includes general chemistry lecture and laboratory classes. When the NSNT course was first offered to students, the instructors were unsure that this prerequisite was sufficient. Another option that was considered was to require a grade of A or B in general chemistry. This grade requirement was found to be unnecessary because, despite the low entrance requirements, only the most enthusiastic and motivated students tend to enroll. This resulted in a class of students who are very interested in learning about nanotechnology, generally knowledgeable about science, and more than competent in the laboratory. The quality of students enrolled in the NSNT course alleviates the instructors from spending class time addressing common misconceptions about the basic science related to the experiment. Given the above-average difficulty of some laboratory activities, it is strongly recommended that similar courses be structured in a manner that attracts above-average students, either through self-selection by students or by using appropriate grade pre-requisites. All this is not to suggest that average students should not learn about nanotechnology, but a course designed for that audience would be somewhat different than the one described here. An alternative approach that might serve a wider student audience would be to provide a separate lecture session so that an instructor can devote more time to explaining topics prior to students performing the experiments.

There are several reasons for introducing nanotechnology to students early in the college curriculum. Students should begin to prepare for future science and engineering careers that will require nanotechnology-related skills and knowledge (*Supplement to the President's 2007 Budget*, 2006). By teaching them about cutting-edge discoveries, first-year students can see where a degree in science and engineering can lead them. The interdisciplinary nature of nanotechnology illustrates to students the connections between seemingly unrelated subjects, such as physics and biology (e.g., using magnetic fields to manipulate nanoparticles in a tumor cell). Learning nanotechnology can help students appreciate subjects like chemistry, even if the subject lies outside the student's major (Condren et al., 2002; Roco, 2003). All this should pique their interest. Students who enroll in courses that interest them are more likely to continue their studies and be successful in college (Condren et al., 2002).

Enrolling non-freshmen in the NSNT class would present several drawbacks. The difficulty level of the experiments is appropriate for freshmen and perhaps sophomores. Juniors and seniors majoring in chemistry, chemical engineering and physics would likely be bored by the experiments and would consider the instructor's presentation of the theory overly simplified. Juniors and seniors might understand the theory and laboratory procedures even less than the freshmen because they completed their last general chemistry class several years ago. A freshmen-only class is easier to teach because they are a more homogenous group in terms of their knowledge and skills.

3. COURSE STRUCTURE

The course is listed in the university's course catalog simultaneously as a chemistry, chemical engineering, and physics course, since these are the departments of the three faculty instructors. Listing the course in this manner emphasizes to students the interdisciplinary nature of the subject matter and advertises it to a wide audience. Cross-listing makes it clear that the faculty instructors are working as a team to teach the course. In addition, all involved departments have an incentive to fully support their faculty teaching the NSNT course. Students from all areas of science and engineering enroll, not just those majoring in the instructors' disciplines. The NSNT laboratory is a one-credit course that partially fulfills Florida Tech's science elective graduation requirement. The lab sessions are scheduled once a week in the evening to avoid conflicts with other courses. Enrollment is limited to 12 students so that each student can have time to operate the scanning probe microscopes and so that the instructors can work closely with all the students.

All three faculty members teach approximately the same number of weeks during the semester. Most introductory science laboratory courses at Florida Tech are taught by graduate students. Students take note of the faculty members' involvement in the NSNT course and appreciate it. Interacting with some of the best freshman students has been the most rewarding part of teaching the class for the instructors. Undergraduate teaching assistants help prepare the experiments and assist the NSNT students during the lab session. This provides the undergraduate assistants an opportunity to learn about nanotechnology and gives them some laboratory work experience.

Each faculty member helps administer the course, which includes submitting grades, scheduling special guest speakers, and organizing lab tours. Creating a non-traditional course such as this requires extra time and effort, so it is important that the faculty team work well together. Based on the author's experience, there are many benefits to team-teaching with colleagues in other departments, besides distributing the workload. Teaching with faculty from physics and chemical engineering has increased research collaborations, provided networking opportunities and promoted positive inter-departmental relations.

Instructors are responsible for designing and supervising their own experiments. This independence is an advantage because it yields a course that presents nanotechnology from three different perspectives. As a chemist, the author is interested in the synthesis and chemical properties of nanomaterials. He supervises the students' preparation of gold, iron oxide (ferrofluid), and cadmium sulfide nanoparticles. The prelaboratory briefings and discussions with students during the experiment focus on intermolecular forces and chemical reactions that produce the nanoparticles and affect their behavior. Dr. James Brenner is a chemical engineer and leads the carbon nanotube and carbon foam synthesis and characterization experiments. Dr. Brenner's previous career in industry and his current research interests lie in applications of nanotechnology, especially for use in the chemical and pharmaceutical industries and the emerging field of hydrogen energy storage. He also teaches materials science and nanotechnology classes for juniors and seniors, so he can advise students about other related courses they might take in the future. Dr. Ming Zhang's research is focused on radiation and energetic particles found in space but he also has an interest in teaching nanotechnology. He oversees the scanning probe microscopy and thin film deposition activities. He teaches the senior-level physics laboratory courses and so he is familiar with a wide variety of scientific instrumentation that is relevant to nanotechnology. Dr. Joel Olson, a chemist with research interests that include STM imaging, is a guest instructor who teaches one experiment in which students chemically etch gold STM tips. It is conceivable that either of the instructors (Winkelmann, Brenner, or Zhang) could teach the entire course, but the presence of all three helps to maintain the course's goal of providing a broad introduction to nanotechnology, and prevents the course from drifting toward becoming an introduction to nanochemistry, nanoengineering or nanophysics.

One potential problem with team teaching is that the grading criteria among the faculty members might not be consistent. This occurred during the first year that the NSNT course was taught. At that time, students wrote weekly laboratory reports. They correctly noted that completing the assignments was difficult and frustrating since each instructor had different expectations and formats for the reports. Subsequently, the grading system has changed so that a student's grade is based on his or her performance in the laboratory sessions (50%) and grades for a research paper and a presentation given to the class (25% each). The weekly laboratory grade is based on the student's attendance, participation in discussions, and following the experimental procedures and safety guidelines. At the end of the semester, students turn in a ten-page research paper and give a ten-minute presentation that describe the current and future applications of a material or technique that they learned about in the course. Since there are so many possible applications for nanomaterials and characterization techniques, students can investigate the topic that interests them the most and each student can choose something different. Students have chosen topics such as *carbon nanotubes in space elevators*, *military applications of nanomaterials*, and *uses of AFM in biological research*. Almost all students use PowerPoint for their presentations and some bring in commercially available items that contain nanomaterials relevant to their topic. Each professor grades the students' research papers and presentations using a rubric that is given to students beforehand so that they know how they will be evaluated (Meyer, 2003). The scores of all three faculty members are averaged for each student. This gives students much-needed experience in writing about technical issues and giving oral presentations. Students prefer this grading system and the instructors are pleased with the quality of the students' work in all areas: laboratory skills, written reports, and oral presentations.

4. LABORATORY ACTIVITIES

All the instructors and undergraduate assistants meet the students during the first class session. After explaining information contained in the syllabus, the instructors ask students to describe what they know about nanotechnology and where they gained that knowledge. Most students respond that they heard about it on a cable TV science show or read about it online. Often, they learn about nanotechnology as a result of their interest in another field, such as future computer technology. Students tend to know about nanotechnology because of its high-profile current and future applications. Students also attribute their familiarity with nanotechnology to science fiction books and movies. This gives the instructors an opportunity to correct some misconceptions about nanotechnology. Only a small number of students enter the class having never heard of nanotechnology.

Faculty provide students with written summaries that include instructions and background information for each class session and expect students to read it beforehand. Each laboratory session begins with a 30 minute discussion of important safety rules, the theoretical background, and experimental procedure. Students' responses during the discussion show if they are prepared.

Students work in pairs or individually to perform nine synthesis or characterization experiments during the semester. Table II lists the schedule for recent NSNT courses. The author recommends that readers consult the literature sources for details about each experimental procedure. Experiments are designed by the faculty or taken from the research and education literature, including web sites such as the University of Wisconsin-Madison's MRSEC video lab manual (http://mrsec.wisc.edu/Edetc/nanolab/). The NSNT instructors have also published a book chapter that describes the laboratory activities in more detail (Winkelmann, Brenner, & Mantovani, 2008). New nanoscience and technology laboratory experiment procedures are published with increasing frequency and so the experiments listed in Table II are by no means the only freshman level nanotechnology experiments available.

Due to their complexity, some experiments span more than one week. Synthesis of multiwalled carbon nanotubes requires that students first prepare the metal oxide catalyst. Afterwards, the instructor and undergraduate research assistants synthesize the nanotubes by reacting methane over the students' catalysts at 600 °C and 1 atm in a custom-made reactor. Obviously, these experimental conditions do not allow first-year students to perform the

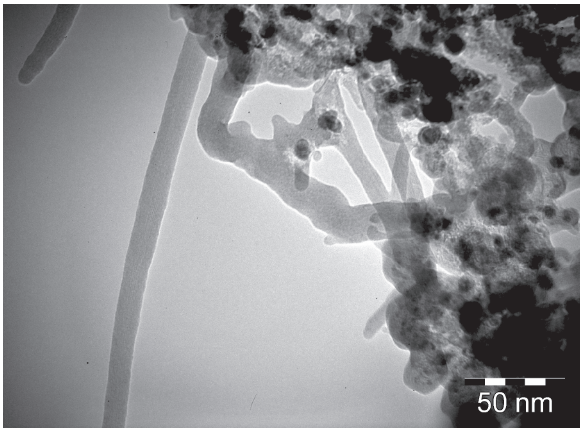

Fig. 1. TEM image of multiwalled carbon nanotubes and metal oxide catalyst synthesized in the NSNT lab course.

procedure themselves. During the following lab session, students prepare the nanotube samples for imaging and view the nanotubes using a transmission electron microscope (TEM). Operation of the TEM is performed by the instructor. A TEM image in Figure 1 shows carbon nanotubes and remaining metal oxide catalyst prepared by students using this method. Performing the synthesis of carbon nanotubes in between lab sessions is not the optimum teaching method but the instructors had to strike a balance between safety, the complexity of the procedure, and introducing students to an important nanotech material. This is the only experiment in which students cannot perform the entire synthesis. As Figure 1 shows, some metal oxide catalyst remains tangled up with the multiwalled carbon nanotubes. If the instructor wishes to use less contaminated carbon nanotubes as a starting material for another experiment or demonstration, the author recommends contacting a manufacturer who will likely donate gram quantities for educational use. This alleviates the need to purchase expensive, high-purity carbon nanotubes.

One of the most noteworthy features of Florida Tech's NSNT course is that each freshman student is provided the opportunity to operate education-grade STM and AFM instruments. Students learn to image surfaces during three lab sessions. Nanosurf EasyScan STM and AFM instruments manufactured by *Nanoscience Instruments* are simple enough for students to operate and provide very good images. Students use the STM to image highly ordered pyrolytic graphite and samples of nanomaterials that they prepare during a previous lab session. Students collect AFM images of metallic thin films, silicone crystals, and carbon nanotubes. The films were prepared by the students using standard sputter coating and thermal evaporation techniques.

In order to prepare students to use the microscopes, an instructor devotes one entire session to an instrument lecture and demonstration. Students then image surfaces during the following two weeks. One of each type of microscope is available to the NSNT students. Half of the students (group A or B, see Table II) attend the session, while the other group has the week off, ostensibly to begin writing their upcoming research papers. This format allows a student to use each microscope for 30 minutes. Prior to the laboratory session, the instructor mounts the probe tip and connects the instruments to the computer so they are ready to be used at the beginning of class. Students mount the sample in the microscope, approach the tip to the surface and record an image. Colliding the tip with the sample surface does occur occasionally and will delay completion of the activity. During image collection, students can adjust some parameters such as scan speed and scan area. Some students can achieve atomic resolution of graphite; all can observe the periodic surface features of graphite and the microstructure of the silicon crystal. Image quality improves if students have more time to collect an image.

Nanosurf EasyScan STM and AFM instruments together cost approximately $40,000. Their cost can be justified by incorporating them into the curricula of traditional courses in chemistry (Aumann, Muyskens, & Sinniah, 2003; Heinz & Hoh, 2005; Lehmpuhl, 2003; Maye, Luo, Han, & Zhong, 2002; Zhong et al., 2003), engineering (Ostrander & Roysam, 1999; Sheppard & Jenison, 1997), and physics (Xiang, Wang, Liu, & He, 2007). Scanning probe microscopes have also been used for outreach activities with secondary school students (Margel, Eylon, & Scherz, 2004). Costs of consumables for the instruments are low. While institutional support for instrument purchases is desirable, other funding sources are also available. For instance, the National Science Foundation funds the development of new undergraduate nanotechnology courses through the *Nanotechnology Undergraduate Education* program or the *Course, Curriculum and Laboratory Improvement* program. The instruments allow instructors to create a valuable learning experience for students and help to provide a balance between "wet-lab" experiments and instrumentation activities.

In the event that instrumentation funds are limited, faculty can design a high-quality, introductory nanotechnology laboratory that focuses less on characterization and more in other areas, such as synthesis or the societal impacts of nanotechnology. Free online simulations of a variety of STM and AFM instruments are available (Nanoscience Instruments, 2008) so that students can learn how different instrument parameters affect the resulting image. While the author feels that a hands-on approach using an actual instrument is preferred, there are some advantages to simulations. For instance, students can spend more time using a simulation program because instrument availability is not an issue, and there are not unanticipated equipment malfunctions.

The unusual chemical properties of nanomaterials raise safety concerns (Colvin, 2003). The instructors selected experiments that minimize the hazards of nanomaterials. Students encounter nanoparticles only in solutions or suspensions with low vapor pressures. Dry powders that can easily become airborne pose the greatest health risks and so they are avoided. When each laboratory experiment is complete, the nanomaterials are either stored for later use as demonstration materials if they are stable or treated so that the nanoparticles agglomerate to form the bulk material, which is then disposed of according to recommended safety guidelines. Instructors inform students about the safety issues during the weekly laboratory discussions.

Although the NSNT course is designed for freshmen, the laboratory experiments provide skills that the students will use if they pursue undergraduate research or a career in a nanotechnology-related field. Students learn simplified versions of the same instrumental techniques and synthesis strategies that researchers use. In fact, the instructors have designed several of the experiments based on accounts from the science and engineering research literature.

Other class activities include seminars and a tour of research labs. Speakers and tours are arranged with scientists and engineers on campus or in nearby research laboratories that are involved in nanotechnology. These events provide excellent opportunities for researchers to talk with instructors and students about their work. Speakers are impressed that they can discuss topics such as atomic force microscopy and carbon nanotubes with first-year college students. Guest speakers from NASA Kennedy Space Center, located one hour from Florida Tech, have presented their research involving nanomaterials in self-healing wires and the use of AFM for imaging bone deterioration caused by weightlessness. Students tour the imaging laboratory at Florida Tech that houses many probe microscopes and other instrumentation that faculty use in their nanotechnology research. Students have also taken a field trip to NASA Kennedy Space Center to tour their science laboratories.

5. EDUCATIONAL IMPACT OF NSNT COURSE

Student evaluations of the NSNT course have been very positive. The most common responses were that students appreciated the multiple perspectives provided by instructors from different fields and enjoyed the opportunity to operate the scanning probe microscopes. Among the synthesis experiments, preparation of ferrofluids is consistently their favorite. A survey of course alumni showed that the course impacted their educational goals. Most students (85%) responded that it helped them prepare for future courses, and 29% credited the NSNT course for helping them get undergraduate research positions. Often, these undergraduate researchers are mentored by one of the NSNT laboratory instructors. One of those students also received a research assistantship at NASA Kennedy Space Center in part because of his experience using the STM and AFM.

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Given the enormous benefits of undergraduate research (Hathaway, Gregerman, & Davis, 2003; Kardash, 2000), a course that can encourage students to pursue this endeavor has great value, especially when students start research early in their college careers (Atwood & Hutchison, 2002; Slezak, 1999). Since the NSNT instructors conduct nanotechnology research themselves, the laboratory course provides them with an opportunity to interact with very talented freshmen who could join their research groups. Those students begin their research projects already knowing much of the background information. As an example, several students who completed the NSNT course went on to perform undergraduate research for the author. Their projects involved creating new laboratory experiments for the NSNT course. These students not only possessed knowledge of the background nanotechnology, they also understood the types of activities would be interesting and appropriately challenging to other NSNT students.

6. FUTURE WORK

The instructors would like to increase the NSNT lab enrollment to serve more students. Additional probe microscopes will be needed so that each student can still operate the instruments. Several former NSNT students have remarked upon the lack of biology-themed experiments. This is the greatest deficiency of the present NSNT course and will be addressed by inviting biology department faculty to become involved in designing and teaching bionanotechnology experiments. Faculty are developing new experiments that involve more complex systems, such as using nanomaterials for environmental remediation and improving the mechanical and chemical properties of composites. Another planned activity is a debate about the societal impacts of nanotechnology. Given the rate at which nanotechnology research is advancing, there will be many opportunities to create new student activities.

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