Building bridges between the engineering classroom and the research laboratory: nanoscience at Union College supported by the NSF NUE program.

Dr. Palmyra Catravas, Union College

Dr. Palma Catravas is a member of the faculty of the Electrical and Computer Engineering Department at Union College, and has a background in electron beam diagnostics for high energy accelerators. Her current research interests extend to scientific visualization, graphical techniques in electrical engineering and art-science endeavors, visual and musical.

Prof. Michael E Hagerman, Union College

Michael E. Hagerman is an inorganic materials chemist who has been active in the integration of nanoscience into the chemistry curriculum. His interests focus on the realization of novel advanced inorganic/organic nanocomposites with applications in chemical sensing, photonics, LEDs and solar cells. His current research involves studies of the self-assembly nanomaterials and inclusion chemistry of Ru polypyridine complexes, CdSe nanocrystals, and polymers within clays, zeolites, and mesoporous materials.

Dr. Brian D. Cohen, Department of Biological Sciences, Union College

Dr. Brian D. Cohen is a biologist with primary research interests understanding endocrine disorders such as infertility on the molecular level. Currently, his focus is on single molecule detection of G protein-coupled receptors by combining fluorescence and atomic force microscopy techniques. Before joining the faculty of Union College, Brian worked with Evident Technologies, Inc., a leading international supplier of QDs. He served as PI on a DARPA award to Evident aimed at developing biological applications for QDs. In addition to team teaching in the nanotechnology course, he teaches molecular biology, biochemistry, endocrinology, and Understanding Cancer, a course for non-science majors.

Dr. Samuel Amanuel, Union College

Dr. Samuel Amanuel is an assistant professor at Union College. His research interest is in applied physics with emphasis in mechanical properties of polymers and polymer nanocomposites. He studies thermodynamics of nanoscaled systems as well. Prior to joining Union College, he was a post-doctoral fellow at Rensselaer Polytechnic Institute where he studied time evolution of nanoscaled crystalline domains in synthetic polymers and their efficacy in the reinforcement of thermoplastic elastomers.

Dr. Rebecca Cortez, Union College

Dr. Rebecca Cortez is a materials scientist in the Mechanical Engineering Department at Union College. Current research interests include the morphological and electrical characterization of nanoscale materials and thin films. Previous research activities involved the fabrication and characterization of radio frequency microelectromechanical systems (MEMS) devices; low-cycle and fretting fatigue testing of metal alloys; and thermal plasma arc processing for heavy metal immobilization.

Mr. Kevin Bubriski, Green Mountain College

Kevin Bubriski is a professor of photography at Green Mountain College. He is a documentary photographer and recipient of the 2010 Robert Gardner Visiting Artist Fellowship at the Peabody Museum at Harvard University. A retrospective book of his Nepal photographs from 1975 to 2011 will be published in 2013 by the Peabody Museum Press.

Mr. Amin Meyghani
Amin Meyghani is an undergraduate majoring in Electrical Engineering at Union College. Previously, he studied in Hong Kong through a United World College Scholarship. His interests include nanotechnology and electron microscopy, software design (cloud or mobile), front-end and back-end web engineering. He is an avid contributor to community service efforts, including work for Ignition Learning and the Crescendo Young Musicians Guild.

Prof. Seyfollah Maleki, Union College

Seyffie Maleki has been a professor of physics at Union College since 1983. His areas of research interest range from optics, atomic, and molecular physics to laser trapping and laser ablation. Most recently, his research area concentrates on scientific studies in support of arts and cultural heritage conservation.
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Abstract. This project focuses on building connections between the classroom and undergraduate research in nanoscience and on developing novel art-science activities as a vehicle for outreach. Through support from the NSF NUE program, we have developed a new undergraduate nanoscale engineering course that provides in-depth coverage of micro and nanoscale microscopy (including atomic force and electron microscopy) in tandem with coverage of special topics in nanoscience/nanotechnology. The course structure is modular, allowing faculty from any of five departments who participate in the nano collaboration to co-teach. The special topic has ranged from self-assembled nanostructures for sensors, solar cells and nanoelectronics in the first two offerings to bionanomaterials (in preparation). Individual, hands-on training in nanoscale microscopy has been designed to complement the special topics coverage during the studio laboratory portion of the course. Students are provided at least two hours per week of supervised instruction on the microscopy tools in groups of two or less. Bridges between the course and undergraduate research are created through the use of samples that are generated by or related to undergraduate research projects with the co-PIs. Undergraduates participating in these research projects have presented at both national scientific conferences and undergraduate research venues. Using the pedagogical material developed for this course, we have produced in collaboration with a documentary photographer a nanoscale microscopy/art-science exhibit. Students in the nanoscience course worked closely with students in an advanced photography course to acquire the images. The exhibit has impacted 4,000 K-12 students and a public audience of about 10,000 people. The five department collaboration and modular teaching approach we employ has enabled us to sustain an interdisciplinary undergraduate program in nanoscience at Union College, a small, liberal arts college, for ten years.

Introduction

We successfully launched a new advanced nanoscience course with the support of the NSF-NUE program. The course was entitled Advanced Topics in Nanoscience: Microscopy of Self-Assembled Nanostructures. This course adds key depth to our interdisciplinary nanotechnology minor and features special topics in nanoscience and nanotechnology, including self-assembled nanostructures for solar cells, sensors and nanoelectronics. This upper level course includes in-depth coverage of micro and nanoscale microscopy, including scanning electron microscopy (SEM) and atomic force microscopy (AFM) and their related modes and diagnostic methods. These microscopy studio labs serve as key bridges to encourage faculty-student interactions, cultivate student interest in careers in nanotechnology, and promote and recruit for our program which links five academic departments (Biology, Physics, Chemistry, Mechanical Engineering, and Electrical and Computer Engineering).

Key topics that were covered in the course included: static versus dynamic self-assembly, atomic force microscopy, scanning electron microscopy, biomimetics,
engineered systems and directed self-assembly, and AFM and SEM studies of inorganic/organic self-assembled nanosystems. Specific nanomaterials featured included: Au and CdSe nanoparticles, dendritic organic polymers, ferrofluids, electrospun polymers, polymer nanocomposites, carbon nanotubes, and hybrid bilayer and bulk solar heterojunctions. The primary texts for the course were: Self Assembly: The Science of Things That Put Themselves Together, by John A. Pelesko, and Atomic Force Microscopy, by Peter Eaton and Paul West. The students also read several review articles from the primary literature focused on course themes including the pioneering work of George Whitesides, Samuel Stupp, Chad Mirkin, and David Ginger.

The learning objectives for the course included: 1) to expand student technical expertise with nanomaterials characterization methods including scanning electron microscopy and atomic force microscopy; 2) to enhance student understanding of the synthesis and characterization of self-assembled nanostructures and their materials applications; 3) to encourage student interest in our undergraduate nanoscience research program in engineering and the physical sciences, the nanoscience minor, and career opportunities in nanotechnology and related fields; and, 4) to build student technical science writing and communication skills through a NanoTracts paper assignment and various outreach activities including a nanoscale microscopy/art-science show that brings together undergraduate nanoscience and visual arts students/faculty and professional microscopists.

The images shown in this paper were acquired with a Zeiss EVO-50 scanning electron microscope and an Asylum Research MFP-3D atomic force microscope.

Bridges between the classroom and undergraduate research

Bridge 1 – Students learn to read and comprehend technical papers from the primary literature through a novel writing assignment – the NanoTracts paper

The process of reading and acquiring an in-depth understanding of peer-reviewed articles from the scientific literature is an essential research skill that is out of the comfort zone of most undergraduate students. These skills are developed with time and practice, and proficiency ameliorates potential for success with research endeavors over their future careers. A term project has been incorporated into the course to teach the students how to read and digest journal articles in the field. The students were asked to select a peer-reviewed article published within the last year that describes new work related to the course theme (for example, characterization of self-assembled nanostructures) and to prepare a paper containing a research condensation and commentary patterned after the format of the journal, ChemTracts. They must search for and read a sufficient number of additional papers to be able to place the work in the greater context within the field. They must independently dig up information about each term in the paper that they do not initially understand until they can clearly explain what the researchers accomplished. Finally, they must synthesize the content of the paper with new material learned in the course and find relevant related papers not referenced in the article being analyzed so that they can not only paraphrase the authors’ results but also suggest new directions for the research. The quality of this final commentary section illustrates the degree to which the students succeed in the assignment.
The NanoTracts term project has been fine-tuned in our core nano courses over a ten year period and is heavily weighted (worth 40% of the grade) in the course being described here. The emphasis of this course on advanced topics makes it especially well suited to such an assignment because the faculty devote significant time in their lectures to recently published material, providing these articles\textsuperscript{3-8} to the students as reading assignments, and illustrating by example how to approach the process. The NanoTracts paper establishes several types of bridges between the classroom and undergraduate research, in addition to basic skill development. Many students have chosen an article from the scientific literature to study that enhances an on-going research project. The genesis of a senior thesis or summer research proposal can sometimes occur through the assignment.

**Bridge 2 – Students enrolled in the course are exposed to ongoing undergraduate research projects through the imaging of samples generated through these projects**

Samples that were generated as part of senior thesis and summer research projects supervised by the authors are provided to students to image during the microscopy labs. In this way, the labs provide an avenue for the students to be introduced to topics featuring on-going research in solar materials, sensors, catalysis and photonics through an active learning process. Particular materials included conductive polyaniline (PANI) and polythiophene polymers, ZnO and CdSe nanoparticles, Laponite clay nanocomposites, and electrospun polyethylene oxide (PEO) fibers. Students also brought samples to image during the studio labs from their own ongoing research projects that included titanium and nickel oxide aerogels and anodized aluminum oxide (AAO). Two examples of AFM images acquired in the classroom by students of nanostructures synthesized through other students’ undergraduate research projects can be seen in Figure 1.

**Bridge 3 – Funding from the NUE supported undergraduate research projects**

The NUE enabled students to work with the authors on both summer research projects and research practica during the academic year. These projects were highly interdisciplinary, and were often co-advised by faculty from up to three departments. Topics ranged from phase transitions of nanomaterials (calorimetric measurements in order to study physical size affects melting temperature and heat of fusion) to the fabrication of nanostructures using electrochemistry, (in which the student anodized aluminum in weak acids in order to generate regular arrays of nanopores and imaged them).

An example of how such a project can bridge the classroom and undergraduate research is illustrated by an eight week summer experience entitled, “Live Imaging of Caveole and FSH-R on Cell Membranes Using Atomic Force Microscopy.” A student worked with one of the authors to develop protocols and techniques for imaging live cells using the Asylum MFP-3D atomic force microscope, an instrument used extensively in the course. After a period of initial training, she grew HEK203 cells expressing the human follicle stimulating hormone receptor and then worked on protocols for imaging cells using the
AFM. Her hypothesis was that using AFM, it would be possible to see invaginations and other structures in the membrane. She worked on refining her protocols to improve her resolution including comparing contact and tapping modes as well as trying different cantilevers to get the highest level of detail. Cells cannot be stored as samples for future imaging in the courses, but the student was trained to grow cells to be imaged de novo as required for the courses. Note that a bio-nano themed offering of the course is underway in Winter, 2013.

Bridge 4 – Testing the waters

The new course developed through the NUE was opened up to students who wished to “test the waters” to see if the material would be of use to them. One student audited a subset of the lectures, and later that summer presented work in the college’s summer research program that featured AFM images of chocolate as part of a study on how the morphology of chocolate is affected by sugar composition and processing conditions such as temperature. This precipitated increased interaction between the faculty supervisor of the student and the nano group, along with ideas for new collaborative measurements that will involve students. In another case, a first year student who was not enrolled in the course was paired with one of the more experienced students enrolled in the course, and completed a research practicum on imaging coffee beans in various stages of the roasting process. The course was also audited by a retired engineer from General Electric, who shared with the students first hand anecdotes on the history of discoveries that have influenced current research, while they were imaging samples in the labs.

Bridge 5 – Students mentoring other students

The microscopy laboratories were time intensive and required a significant investment by the faculty to bring to fruition. Every group of two students received an average of two hours per week of direct training from faculty on either the AFM or SEM, for ten weeks. This level of student-faculty interaction proved to be a worthwhile investment. Within a year following his completion of the course, one junior-year chemistry major devoted well over forty hours (compensated) to independently train two other students on material covered in the studio labs in order to facilitate their undergraduate research projects. One trainee was preparing for a project on the nanomorphology of sugars and the other a project on mechanical characterization of biological samples. This student wrote:

My ability to mentor my peers on the AFM was entirely due to ESC324. My understanding of AFM techniques was greatly enhanced as a result of that class, and I grew much more comfortable with the instrument. The course also taught me how to mentor others on AFM techniques, as the faculty teaching the course were masterful at explaining the technique to students with little experience.

The course was also invaluable for my own research. As a result of the class, I became proficient in tapping mode and was able to engage on my research samples nearly 100% of the time, a feat thought impossible
before. I also learned force spectroscopy, as well as gleaned insight into how modifying AFM probes could be incredibly beneficial; both of which are now vital to my own research in nanomorphology.

Outreach

We incorporated the production of an art-science exhibit into the course both as a pedagogical exercise and as a means of performing outreach. Students in the microscopy laboratory were paired with students taking an advanced photography course taught by a Visual Arts faculty member with expertise in B/W photography. The interdisciplinary student teams acquired images (Figure 2) for a contest co-judged by a group of professional microscopists from local industry and neighboring academic institutions and by two faculty from the Visual Arts Department at Union. The students received feedback from the two groups of judges on the scientific and the artistic aspects, respectively, of their images. In order to take good images, the visual arts students needed to communicate the principles of composition and aesthetics learned in their home course to the nano students. The nano students needed to be able to communicate what could be accomplished with the instrumentation to the visual arts students and operate the instrument in response to requests from them. The fluency acquired in obtaining nanoscale images as a result of this exercise was remarkably improved compared with our previous experience. Prints of select images were displayed in the art gallery on campus, and the exhibit travelled to the Gateway Science Museum in Chico, CA, where it was seen by about 10,000 public viewers, including 4,000 K-12 students on guided field trips.

As a follow-up to this group experience in the classroom, one of the students who took the class (an electrical engineering major with a strong interest in community outreach) has been working on creating an independent exhibit of his own. Some of his images are shown in Figure 3.

Conclusion

Through support from the NSF NUE program, we have developed a new advanced topics course in nanotechnology geared for undergraduates that enriches our nanotechnology minor, that features a topical lecture module and an intensive hands-on microscopy experience. This course has enabled us to investigate a variety of bridges between the classroom and undergraduate research: the NanoTracts paper for teaching students how to approach reading the primary scientific literature; the classroom use of samples synthesized as part of undergraduate research to inspire other students; the direct supervision of research projects; increased faculty collaboration that has spawned new research opportunities for students; and peer-to-peer mentoring. The course, which has received permanent course approval from the college, is currently in its third offering. The course is amenable to generating visually striking outreach products, which have been presented to 4,000 K-12 students on field trips. The course has not only produced students able to independently mentor other students, reducing their learning curve for
undergraduate research, but also students with the nanoscale microscopy skills to significantly expand the impact of our outreach efforts.

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Figure 1. Students have imaged a variety of nanomaterials synthesized by other undergraduates as part of the course. Plates a)-c) show AFM images of Laponite synthetic clay thin film on quartz with nanodisks of diameters under 100 nm. Plates d)-e) show electrospun polyethylene oxide nanofibers. The top row, from left to right consists of AFM amplitude and phase images for the Laponite and electrospun fiber samples, while the bottom row provides the 3-D height profile. The images were acquired with the MFP-3D atomic force microscope, manufactured by Asylum Research.
Figure 2. Students acquire images with the atomic force microscope during the microscopy labs.
Figure 3. A student who completed the course is creating an independent art-science exhibit. The electron microscope images shown all seek beauty, often overlooked, in the elements underlying the microscopy imaging process or construction. The samples and (their horizontal field widths) are: a) debris from building construction (840 um); b) solder (475 um); c) and d) indented SEM stub (890 um, 1.24 um); e) TEM grid (200 um); f) and g) debris from STEM stub (250 um, 140 um); h) and i) solder (130 um, 1.01 mm). Images were acquired with a Zeiss EVO-50 scanning electron microscope.
References: