# Frontiers of Nanotechnology and Nanomaterials

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## Abstract

Union College's student body combines about 15% engineering students with a predominately liberal arts campus of approximately 2,000 students. Recently the College embraced an interdisciplinary program "Converging Technologies" that integrates cross curricula material into existing core engineering and liberal arts programs.

We have developed an undergraduate course "Frontiers of Nanotechnology and Nanomaterials" aimed at sophomore engineering and science majors with prerequisites of mathematics through calculus, a first sequence in physics, and one course in chemistry. Important goals were to bring the excitement of nanotechnology to students early in their scholastic careers and to make them aware of the many opportunities for research and further study.

The pedagogical challenges were several. We needed to: 1) reflect existing faculty interests in engineering, physics, and chemistry, 2) integrate those faculty into a cohesive teaching unit, 3) be intelligible to sophomores, juniors, and seniors, 4) serve a multidisciplinary student body, and 5) have assessable outcomes. In addition, no single ideal text was available so several sources of ancillary readings were assigned.

Since contemporary research in nanotechnology and nanomaterials is normally too advanced for sophomore students, several innovative techniques tested their assimilation of course materials. Quantitative and semi-quantitative aspects were evaluated using weekly homework and two in-class exams. Qualitative understanding of the material was tested by requiring student teams to orally present important nano-subtopics and have each student to write a self-selected (but faculty approved) "Nanotracts" paper. The Nanotract papers condensed, and critically commentated on, very recently published research papers in the nano field at the full publication standards of the peer research literature.

The course facilitated key contacts with local partner industrial and academic institutions including IBM, General Electric R&D, RPI, Wadsworth Center (a New York state laboratory), and the Albany NanoTech Center. Six expert outside speakers delivered key lectures.

Through a recent NSF-NUE grant, we are developing nanotechnology-teaching modules to expose students to methods of synthesis and characterization of nanomaterials, and a web-based undergraduate textbook on nanomaterials.

## Introduction

Founded in 1795, Union College has a long tradition of innovation in its science and engineering programs. It was among the first colleges to offer chemistry (1809), to create a bachelor's degree in science and mathematics (1822), to establish a degree program in civil engineering within a liberal arts context (1845), and to establish an electrical engineering department (1895). The EE department soon became one of the premier EE departments in the US under the long-term leadership of Charles Proteus Steinmetz, who was simultaneously the Chief Engineer of General Electric (whose manufacturing facilities were situated just a mile away from campus). The current engineering department also includes engineering science, mechanical engineering and computer engineering.

It is the mantra of every forward-looking engineering department to continually update and upgrade their course offerings to avoid educational obsolescence. At Union College, this is a particular and perpetual challenge since the engineering division is just 15% of the student body of a predominantly liberal arts college. As such, the engineering program must be, and must be seen to be, responsive to a changing social climate in an increasingly technological world. As part of its educational program in 2001, the College embraced the interdisciplinary program called "Converging Technologies" [1]. Originally conceived under a national umbrella program to combine several branches of technology to "improve human performance"[2], its major proposed elements were nanotechnology, biotechnology, information technology, and cognitive science.

Union's CT program[3] slightly narrows the focus of the national program; it currently includes five emerging technology fields: bioengineering, mechatronics, nanotechnology, neuroscience, and pervasive computing. However, CT is intended to be organic in scope and to keep abreast with emerging fields. Five faculty committees initially began to examine Union College's existing curriculum to determine the feasibility of implementing new courses and/or modify existing courses, and to generate interest and excitement on campus in support of CT.

Union's intent is to focus creative thought from engineering and from the liberal arts on the new ideas that will change the landscape of global society. Such ideas, which spill across disciplinary boundaries, are expected to define innovation in the 21st century. Students will find courses, programs, and research opportunities in these and other emerging interdisciplinary fields. Both technical and non-technical courses are offered in small classes and laboratories where faculty and students closely interact. As part of this thrust we have developed an undergraduate course "Frontiers of Nanotechnology and Nanomaterials" aimed at sophomore through senior engineering and science majors, as well as interested liberal arts majors. Union College regards this course as one of its core elements in the CT program.

## Course Structure

The first challenge in developing a nanotechnology course was to find like-minded faculty with overlapping and complementary skills. Working in a small liberal arts school such as Union, with its requirement that all students be exposed to all Divisions within the College, made it relatively easy to discover where there were faculty in different departments with the necessary preexisting and overlapping interests in several different areas of nano-technology/materials.

The teaching team's basic skill sets were in chemistry, physics and engineering. Having established a qualified teaching triumvirate for the course, it became necessary to agree upon the course level and content, the course text(s), the course prerequisites, and most importantly, on objective measures for course grading. The last of these was a significant challenge since, by common consent of the teaching triumvirate, the course was open even to sophomores from across the Union student body. Because "nano-technology" embraces a number of disparate disciplines, we decided to initially confine ourselves to a subset of relevant technologies.

| | |
|---|---|
| *Physics:* | Optics, quantum mechanics, condensed matter and laser physics, surface physics, and X-ray diffraction |
| *Chemistry:* | Supramolecular chemistry and self-assembly, introductory organic chemistry, introductory biochemistry, catalysis, polymers, and aerogels |
| *Materials Science:* | Magnetic materials, memory devices, smart materials, ceramics, alloys, carbon materials, and hard ceramics |
| *Engineering* | Multifunctional scanning probes, Langmuir-Blodgett films, MBE and CVD deposition methods, bio-arrays, and MEMS |

The course met twice weekly for 110 minutes for a ten week trimester; the layout of the course is given in the attached table[4]. There were a number of innovations and compromises that were made to fit the course into the available time slots. Unfortunately there was no class slots open for laboratories in this initial offering.

| Week | **Lecture period 1** | **Lecture period 2** |
|---|---|---|
| 1 | Introduction & Course Policies | Design & Fabrication: Advanced Materials<br>Read: Sc. American articles pages 32-37; 39-47; & 59-64 and Text (P. Ball[5])<br>Introduction: Little Big Science |
| 2 | Wave Optics - Theory<br>Read: Text (P. Ball) Chapter 1 | Ray Optics<br>Read: Text (P. Ball) Chapter 2 |
| 3 | Quantum Theory<br>Read: Sci. Amer.[6]: "Plenty of room Indeed" pages 48-57 | Quantum Applications<br>Read: Text (P. Ball) Chapter 3 |

| | | |
|---|---|---|
| 4 | *E. Lifshin, Albany School for Nanosciences and Nanotechnology*: Methods of nano-characterization* Read: Text (P. Ball) Chapter 10 pages 384-400, 404-407, & 415-427 | **Student team presentation 1:** Optoelectronics **Student team presentation 2:** Quantum Dots Discussion of NANOTRACTS I |
| 5 | Exam 1 Integrated Electronics Read: Sc. American article pages 58-64 | Supramolecular Chemistry & Self-Assembly Read: Articles from Science & NANOLetters Home Work Problems on Self-Assembly |
| 6 | Biomedicine & Nanomaterials Read: Text (P. Ball) Chapters 4 & 5; "Less is More...", Sc. Amer. pages 67-73 | *J.Turner: Wadsworth Center,* Bionanomaterials. Electrochemicals/Solar Cells Clean Energy Read: Text (P. Ball) Chapter 6 |
| 7 | **Student team presentation 3**: Nanomaterials for Medicine Porous Materials & Catalysis Read: Text (P. Ball) Chapter 7 *A. Alizadeh, GE Global Research Center,* Synthesis of Nanomaterials | Controlling the Inner Architecture of Materials Read: article from Chem. Mater[7] Tunnel Vision Lecture Tunnel Vision Study Questions |
| 8 | **Student team presentation 4**: In/organic Nanocomposites Self-assembly from the gas phase I: Topsy-Turvy Home-work: Self-assembly from the gas phase; Problem Solutions Read: Text (P. Ball) Chapter 8 | Self-assembly from the gas phase II ***Visit by Dr. Ball*** |
| 9 | *G. Ramanath, RPI,* Nanocarbons, Synthesis and properties Self-assembly from the condensed phase I. Read: Text (P. Ball) Chapters 9 | Exam 2: Chemistry Review Self-assembly from condensed phase II Read: Text (P. Ball) Chapters 10 pages 396-398, 400-404, and 407-415 |
| 10 | **Student team presentation 5**: Nanocarbons **Student team presentation 6**: Langmuir-Blodgett films Discussion of NANOTRACTS II | *Dean D. Klein, Director of Center for CT, Union College*: Ethics in Nanosciences, Nanobots & Nanorevolution Read: Sc. American article pages 74-91 |

**Table 1: Overview of Nanocourse, 2003**

* Talk titles are representative of content and not verbatim as supplied by their authors.

In the above table, course reference books and journals are cited in first order of appearance; student team presentations are **emboldened**, exam periods are underlined and invited expert lecturers are *italized*. The texts included P. Ball, "Made to Measure"[5], a Scientific American special issue[6,] and a Chemistry of Materials special issue[7] and some selected readings from the current research literature.

Much of the mathematics associated with research topics in nanotechnology is well beyond any reasonable expectation of students' sophomore-level capabilities. This eliminated those standard testing and assessment methods in science and engineering courses that required students to show their applied mathematical prowess as proof of their mastery of the material. The evaluation methods therefore were mixed; there were two one-hour exams in class time that used traditional grading techniques as well as weekly homework. In 2002/2003 we also required the students to give a team presentation assigned by the faculty in these major nanomaterials areas: Optoelectronics, Quantum Dots, Nanomaterials for Medicine, Inorganic and Organic Nanocomposites, Nanocarbons, and Langmuir-Blodgett Films. In 2003/2004 these were slightly upgraded to: Molecular Electronics and Nanomaterials, Quantum dots, Nanocarbons, Self-assembled monolayers, Nanocomposites, and Bionanomaterials.

In addition, we required individual students to write a condensation and commentary of a research paper in nanotechnology that had been published within the previous 12 months. We called these papers "Nanotracts" after the journal "Chemtracts"[8]. Each student had to meet with one of the course advisers, select a research paper in the burgeoning nano area, write a preliminary condensation of the chosen article, and write a final paper including commentary. The students were taught to retrieve research articles using "the Web of Science"[9]. Typically the students selected articles from NANOLetters[10] although for the current year's teaching of the course, we have discouraged this particular journal on the basis that this (and other) journal "Letters" publications already tend to be succinct and do not allow full scope for meaningful condensation of content.

Union College is located in the Capital District of New York State, which has some high tech credentials and indeed is promoting itself as "Tech Valley"[11]. Certainly its immediate local nanotechnology resources are impressive: they include the Albany NanoTech Center (associated with the School of Nanosciences and Nanoengineering at the University at Albany), RPI's Nanoscale Science and Engineering Center (funded by NSF), the GE Global Research Center, nearby IBM laboratories, the Wadsworth Center (a NYS operated biology and biotech research laboratory), the east coast laboratory of International Sematech (a global consortium that represents about half the world's semiconductor production), the U.S. research arm of Tokyo Electron, Ltd., Evident Technologies (a developer of Quantum Dots and associated with Siena College – itself another local resource) and a number of others. Those whom we have approached have been willing to cooperate with Union College since they view the current Union nano-course as potentially educating a needed emerging class of "nano-savvy" graduates. As can be seen in the above table, several of the "outside" lecturers were recruited from these organizations; they brought the depth of experts to the course. All students were required to attend these talks. One other eminent visitor who spoke to the student body was Dr. Philip Ball, the British author of several prize winning “popular” scientific texts including “Made to Measure”, one of the primary texts used in this course.

Grades were assessed as follows:

| Academic year | 2002/2003 | 2003/2004 |
|---|---|---|
| Two in-class exams | 40% | 30% |
| Nanotracts paper | 25% | 25% |
| Nanomaterials student team presentation | 20% | 15% |
| Nanoapplications student team poster presentation | - | 15% |
| Homework and class participation | 15% | 15% |

**Table 2: Course grading basis**

One innovation in 2004 we introduced in 2003/2004 was to split the student team presentation into two parts – a presentation, typically web based and delivered in Power Point, and a poster presentation based on an application of the nanomaterials that the students had reviewed in their presentation.

**Course materials assessment**

The primary course text by Philip Ball, even though it is very elegantly written, is not a nano-text *per se*; rather it is a descriptive introduction to modern materials including bio, chemical and electronic materials, although with many chapters being directly applicable to nanotechnology. The level and clarity of the book was excellent for our purposes but its coverage was not completely parallel to the aims of this course. Nevertheless, as a pedagogical decision for the convenience of the student body, we decided to follow the text as closely as possible in terms of the in-class lectures. Therefore some topics, such as a chapter on modern materials for clean energy, were not really germane to the course structure but were included to fully integrate the text into the lecture course. (We were able to review several new nano-monographs that became available in late in 2003 and were able to eliminate this problem for 2004 by choosing among the newly issued texts. For 2003/2004 we chose a new text by Poole and Owen[12]). The “special issue” texts were very successful at introducing many of the concepts behind nanotechnology and to introduce the students to cutting-edge leaders in the field. As nano research progresses we anticipate there will be additional reviews to replace these sources, but for the moment they are excellent reference materials.

As a measure of the effectiveness of Nanotracts as a vehicle to get students interested in nanotechnology research, one (rising senior) student has jointly published a research condensation and commentary with one of the current co-authors. This paper[13] critiqued an

American Chemical Society journal article from *J. Phys. Chem. A,* entitled "Layered Nanocomposites of Aggregated Dyes and Inorganic Scaffolding" and which focused on a specific clay/organic dye nanocomposite with applications for solar energy.

The student assessments of the course faculty (required of every course at Union) naturally focused on the discrepancies in style and in nomenclature among the teaching triumvirate. This was exacerbated by the fact that texts were several as were other sources used by the students. For this reason we have now prepared an extensive web book for 2004 and beyond that should go a long way to unify perceived course discrepancies (see below).

**Conclusion and Challenges**

What worked and what didn't? The outstanding success was undoubtedly the Nanotracts requirement. This was an individual student task but one requiring extensive faculty mentoring. It pushed the students into areas and levels that really stretched both their imagination and skills.

The team presentations, nominally three students per team, were also very high level; their teaming skills were particularly improved by the multidisciplinary nature of most of the teams. The students universally chose Power Point presentations that incorporated web resources with original research from the Web of Science database.

As can be seen from Table 1, the outside lecturers were experts in their respective fields but lecturers who gave talks of an appropriate level for the students. The students seemed to appreciate these speakers in that they brought considerable authority to the course (while reinforcing what was taught in the formal lectures). The homework and exam requirements were nominal as for any engineering or science course.

The biggest challenge was the internal cohesion of the course since it was taught by a triumvirate with mixed backgrounds, discrete teaching skills, and each carrying their specialty's particular language. For the course in 2004 (and presumably useful beyond this date) we obtained a NSF NUE (Nanotechnology Undergraduate Education) grant[14] for $100K to create a web book. This book is becoming available on our course web site[4]; compared to the 2003 course, the material is more fully integrated within each subject area of nanotech and is in a semi-archival format so the students will have access to it. Perhaps more importantly, as an NSF-sponsored grant, it will be on-line for any users to incorporate into their own course structures.

The following modules are currently complete or under development:

- Introduction to Nanotechnology
- Scaling Laws
- Quantum dots, wires, and wells
- Characterization tools for nanomaterials
- Magnetic nanomaterials and spintronics
- Inorganic/organic nanocomposites
- Bionanomaterials

Each subject is linked to a number of other internal modules and/or to a number of external links. We believe the availability of these lectures in these stand-alone formats will go far in meeting the students' concerns about the connectivity and continuity of subject matter. In addition, the web modules are designed to be used in existing *non-nano* courses as another vehicle to bring nanotechnology to the undergraduate curriculum.

Possibly, in the future, the teaching mix will change and allow different emphases in the subject area; fortunately there is essential support from the Union College administration to allow an interdisciplinary triumvirate to teach a modest sized class. In our opinion, probably at least two instructors will be needed to teach this (and probably other) CT courses since, at the level the course was being offered, the necessary technical breadth is unlikely to found in just one teacher.

The next challenge for this course will be to add a laboratory component; this will be necessary in most cases to count this (and similar courses) as part of a future major or minor. In fact, we had already built a considerable capability in a "nanoscopy" laboratory using mostly generously denoted equipment from IBM; this laboratory contains a state-of-the-art optical microscope, two SEMs (one with an energy-dispersive X-ray capability), a student-version STM, and an AFM. The last was originally used to test large sheets of integrated chips and comes with substantial capabilities for chip scanning. So far we have been unable to fit these assets into our course for two good reasons: the prohibitive time to set up the labs and, even more difficult, to find the time to fit in a laboratory into the already crowded schedule.

The laboratories we intend to develop include some in self-assembly, in Langmuir-Blodgett films, in the synthesis of magnetic nanocomposites, in the imaging of magnetic domains (spintronics), and in scanning probe methods (STM & AFM). In addition, we intend to continue our collaboration with the Albany NanoTech Center in order to expose any self selected student to a further involvement at one of the world's largest nano labs. We are also proposing a reciprocal relationship with the Interdisciplinary Education Group of the Materials Research Science and Engineering Center for Nanostructured Materials and Interfaces[15] at the University of Wisconsin. This group has already posted a series of demonstration nanolabs, some of which we would directly incorporate into our own program. Of course, as we develop these laboratories, we will have to solve the perennial problem of trading off time spent in the lectures to the time spent in the laboratory.

We believe we have made a good start to this subject. We have developed a course in an advanced topic area that modestly qualified sophomores can take (with one particularly successful datum point being a liberal arts major). We have been fortunate in our location in New York's Capital District in that it has fostered a number of contacts with large laboratories working in the nanotech area. We believe that the web book modules that we are writing under existing NSF funding will be a lecturing asset. In spite of the extra faculty effort involved, we believe that the "Nanotracts" concept has been the successful core of this course and we hope to incorporate a number of nano labs into the curriculum in the near future.

## Bibliography and notes:


1. Balmer, R. T., “Converging Technologies - The New Frontier in Engineering Education,” Proc. 2002 ASEE, Annual Conference, Montreal, June 16-18, 2002.

2. Roco, M.C. and Bainbridge, W.S., "Converging Technologies for Improving Human Performance", NSF grant CTS-01288 60 (June 2002); see also: Workshop co-sponsored by the National Science Foundation, the Technology Administration and the National Science and Technology Council, Washington, DC, December 3-4, 2001 **http://www.technology.gov/PhotoEssays/Pht011203.htm**

3. **http://www.ct.union.edu**

4. The current table is available on line as one of the links from the current course web site. This site has many internal links to the full course content including lectures, policies, homework, course instructors etc. **http://frontiersofnanotechnology.union.edu**

5. Ball, P., “Made to Measure: New Materials for the 21st Century*”,* Princeton University Press: Princeton, 1999

6. Scientific American: “The Science of the Small Gets Down to Business”, Special issue, September, 2001

7. Chemistry of Materials*,* “Inorganic-Organic Nanocomposites” Special Issue, October 2001.

8. Data Trace Publishing Company: “Chemtracts” provides updates on the newest trends and developments in chemistry by summarizing and commenting on current and past chemical research. **http://www.datatrace.com/chemistry/**

9. Web of Science is a searchable index that connects to several other indices. **http://www.isinet.com/isi/products/citation/wos/**

10. NANOletters is an American Chemical Society journal dedicated to Nanoscience and Nanotechnology. **http://pubs.acs.org/journals/nalefd/**.

11. **http://www.techvalley.org/**

12. Poole, C.P. and Owens, F.J., "Introduction to Nanotechnology", Wiley-Interscience, 2003

13. Iannacone, J. and Hagerman, M.E., *Chemtracts: Inorganic Chemistry*, **16,** 749– 758 (2003)

14. NSF-NUE # 0304105: “Frontiers of Nanotechnology and Nanomaterials”, PIs: S. Maleki, M. Hagerman and P.G. Kosky.

15. **http://www.mrsec.wisc.edu/edetc/nanolab/index.html**


## Biographical Information

P. G. KOSKY has been the GE Distinguished Research Professor of Mechanical Engineering at Union College, Schenectady, NY since early 2001. He obtained his PhD and MS degrees from the University of California at Berkeley and his BSc at University College London in Chemical Engineering. He spent 32 years as a staff scientist with the GE R&D Center in Niskayuna, NY. He has written or presented about 180 papers, reports, and patents.

M. E. HAGERMAN is an Associate Professor of Chemistry at Union College, Schenectady, NY. His doctoral studies were in inorganic materials chemistry at Northwestern University; he developed his undergraduate teaching and research program as a Camille and Henry Dreyfus postdoctoral fellow at Northern Arizona University. He focuses on novel advanced inorganic/organic nanocomposites with applications in chemical sensing and photonics.

S. MALEKI is an Associate Professor of Physics at Union College, Schenectady, NY. He has conducted research in theoretical, experimental, and computational physics. He has developed web-based text and laboratory resources for several courses, ranging from introductory to advanced courses for majors, science majors and non-science majors. He has team-taught courses with a historian, a mathematician, a biologist as well as with several physics colleagues.