

Nanotechnology, Biology, Ethics and Society: Overcoming the Multidisciplinary Teaching Challenges

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ABSTRACT

One of the inherent challenges of teaching any emerging technology like nanotechnology, is the fact that its core competencies flux in the new disciplines' early stages. Nanotechnology presents an additional challenge in that its underpinnings cross multiple traditional disciplinary boundaries. We have designed a course that aims to address some of these challenges through a handful of structural features: team-based learning; a "reverse of the learning pyramid" approach; team-teaching; embedded information literacy techniques; and application-centered content. Our course is organized around four applications that are in their developmental stages: gold nanoshells for cancer treatment; molecular manufacturing; tissue engineering of a vital organ; and a microfluidic glucose sensor. These applications provide natural contexts for learning biology at the cellular level, the molecular level, the organ level and the biological systems level, respectively. They also provide natural contexts to introduce ideas of scientific uncertainty in emerging fields. In this paper, we will present the design features of our sophomore-level course *Nanotechnology, biology, ethics and society* the pedagogical rationale.

INTRODUCTION

Nanotechnology presents a particular challenge for educators because it draws from several disciplines. As an emerging technology, many of the newest developments in this field exist in primary literature, such as journal articles (rather than secondary, such as textbooks). Additionally its potential applications, such as biomedical devices or detection systems for biological warfare, are also intimately tied to societal issues. Combined, these aspects of nanotechnology create a rich learning opportunity for educators to explore ethical and societal implications of nanoscale science and technology while building students skills to critically think.

This paper describes the structure of our sophomore-level course, Nanotechnology, Biology, Ethics and Society, and results showing changes in students' attitudes and motivations.

COURSE STRUCTURE

Our course, designed by a multidisciplinary team of faculty, strikes a balance between depth and breadth by exploring four applications of nanoscale science and engineering (NSEE). It was geared toward sophomores in science and engineering majors; each had a year of chemistry, physics and calculus. As shown in Figure 1, the four nanotechnology examples that we chose span four levels of complexity in biology: the cell level, the organ level, the biological systems level and the ecological level. Each application is intimately tied to NSEE and biotechnology and serves as a complete learning module. Figure 2 depicts the teaching framework for each application: we presented each module by starting with the NSEE application; we proceeded to

its scientific underpinnings; we completed the application with exploring its ethical and societal implications. The module begins with the application as a means of “hooking” students’ interest and providing a motivation for them to learn the material.

The format of the course drew heavily from the well-researched *team-based learning* strategy¹ in which the instructor creates formal groups of five to seven students on the first day of class and students negotiate the weighting for individual and team performance. During class, students engage in carefully-designed applications of the reading materials in their teams. Class time spent on each module (three to four 2-hour sessions) is structured to ensure individual accountability and promote the development of higher-order cognitive skills (i.e., the ability to apply the material that is learned).

FRAMEWORK FOR PRESENTING EACH FOCAL POINT

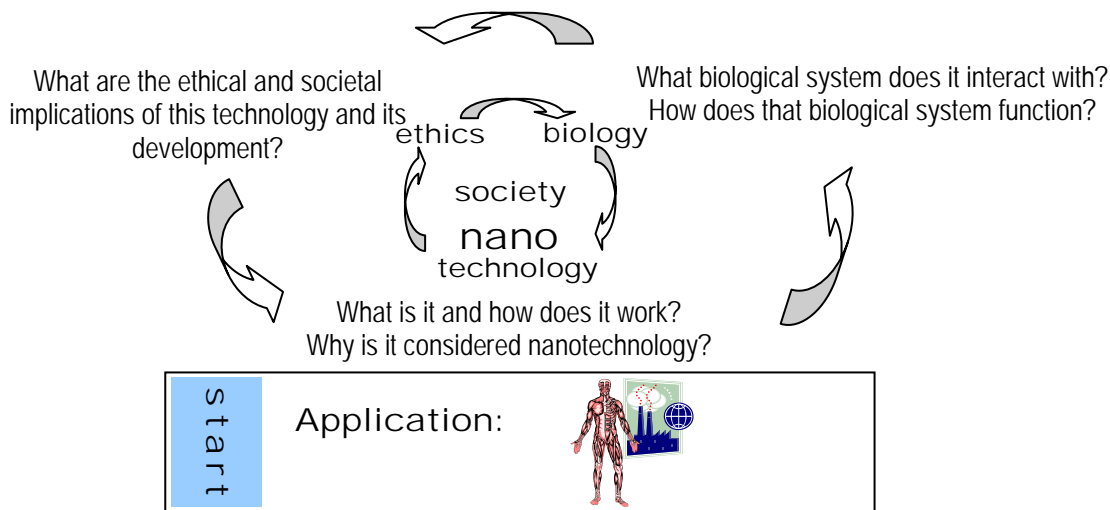


Figure 2. Module Structure. Each module begins with the application.

The general flow of each 2-hour session is depicted in Figure 3. As shown, individual accountability is ensured through individual quizzes. This is followed by a team quiz, an opportunity to write written rebuttals, instructor input and/or feedback, a group activity, and simultaneous presentation of team results.

Primary information sources (versus secondary, such as textbooks) constitute the assigned reading. Researchers involved in NSEE provide mini-lectures (20 minutes) in select class periods. After the four modules (roughly 80% of the course), student teams are assigned a debate issue that bridges NSEE, ethics and society. They are given one week for their team to research the issue. In lieu of a final exam, the course culminates in structured team debates in which they are assigned the *pro* or *con* perspective and given 15 minutes to prepare their arguments. The debate judges, who are given clear instructions on the scoring criteria, include faculty outside the course and fellow students.

Detailed content of the modules: Designed to develop higher-level cognitive skills

We designed each module to pique the interest of female students, based on studies that show women who choose engineering and science as a profession often do so out of a desire to help society.^{2,3} For engineering in general, it is rare for curricula to contain clear connections between the engineering profession and helping society. Among those that do, such as

biomedical engineering and environmental engineering, the national proportion of female graduates has grown to around 45% and 41%, respectively, whereas it is closer to 15% for fields such as mechanical engineering or electrical engineering.⁴ In a nutshell, we designed the modules to clarify how science and technology can positively contribute to society.

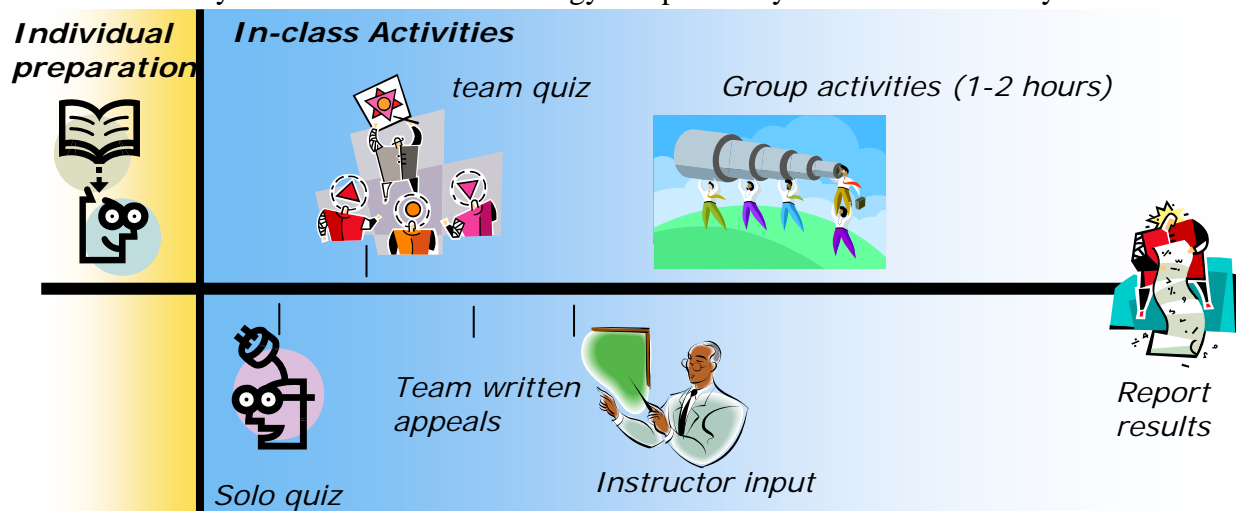


Figure 3. Format of each class session. Students prepare prior to coming to class by completing assigned reading. The quizzes and appeals takes 30-40 minutes.

Table 1 outlines the reading and activities for five modules (1-4 of which we have piloted to date). As indicated, we begin with the idea of molecular manufacturing. This module topic, because it has been speculated that molecular manufacturing will replace 20th century manufacturing techniques⁵, provides a context to discuss manufacturing and its impact on the environment (i.e., it encompasses the *ecological level*). It allows us to introduce the fundamental nanotechnology concepts of *molecular recognition* and *self assembly*. Dr. Pete Schwartz gives an introductory lecture on his work in self-assembly of nanospheres⁶ and the role of scanning probe techniques⁷. It also serves as a platform to introduce means of evaluating scientific authority of authors and publications. Our librarian (BS) guides the students on how to utilize electronic search tools and takes them through an exercise on systematically evaluating the authority of an information source. The first module sets the stage for addressing the ethical issues. The modules that follow incorporate engineering computations.

At first glance, some of the activities look far beyond the capability of the sophomore students (e.g., activity in the tissue engineering of an organ: “Based on the hepatocyte cell dimensions, microblood vessel dimensions and artificial liver design constraints listed in the reading, design an implantable tissue scaffolding for an artificial liver using planar microfabrication technology.”) These activities are designed to bring together the course material in a challenging application that requires a team effort. They utilize the well-documented effective learning technique called *cooperative learning* or *group learning*, which has been shown to result in a greater depth of understanding (for example, see Springer, Stanne and Donovan⁸ or Colbeck, Campbell and Bjorklund⁹). These activities engage students in the process of *applying* their knowledge, promoting the development of higher levels of cognitive functioning. More often than not, courses emphasize the lower cognitive levels, such as *knowledge* and *comprehension*. Higher cognitive levels, such as *application*, *synthesis*, *analysis* and *evaluation*¹⁰ are required by the interdisciplinary and complexity of NSEE. The activities give them opportunities to experience mastery of the material, a quality that has been shown to be the single-most

influential source of students' belief that can accomplish their goals¹¹. Unsurprisingly, this belief has been strongly-linked to persistence in a difficult endeavor¹², such as majoring in science and engineering fields of study.

In the exercise on tissue engineering, students have read a document on tissue engineering scaffoldings, and have had mini-lectures (~20 minutes) on microfabrication and the function of the liver. They are given enough information to come up with a design concept which includes artificial vascular channel dimensions and total device geometry. Clearly, there are several other issues that would come into play in a full device design (e.g., fluid dynamics). We don't expect them to address all issues. The exercise of designing the scaffolding helps them think through and apply the concepts. It provides an opportunity for them to apply their background knowledge as well as the knowledge that they learn during the course. In the "real world," this exercise would be among the first steps to develop ball-park figures for the design of a tissue engineered liver scaffolding.

Table 1. Listing of module reading assignments, lecture topics and activities for modules 1-5. The lecturer for the mini-lecture is indicated by the initials in ().

1: Molecular Manufacturing	Reading	“Voodoo Science, The Seven Warning Signs of Bogus Science,” (Robert L. Park) ¹³ “Self Replicating Systems and Molecular Manufacturing,” (Ralph Merkle) ¹⁴
	lectures	Ecology fundamentals (MR); Manufacturing practices (LV); Evaluating information and its sources critically (BS)
	activity	Critically evaluate Merkle reading against the criteria in the Park article and the mini-lecture material. Identify the statement in the Merkle reading that most undermines the scientific credibility of the document.
	Reading	“Little Big Science,” <i>Sci. American</i> : Sept. 2001 (Gary Stix) ¹⁵ “Machine-Phase Nanotechnology,” <i>Sci. American</i> : Sept. 2001 (Eric Drexler) ¹⁶ “Of Chemistry, Love and Nanobots,” <i>Sci. American</i> : Sept. 2001 (Richard Smalley) ¹⁷
	lectures	Molecular recognition and self-assembly in the context of DNA replication (MR); self-assembly of nanospheres and the role of scanning probe techniques (PS)
	activity	Based on the U.S. Federal government spending (budget data) and Health 2005 (Center for Disease Control), recommend the amount of an increase or decrease in spending for nanotechnology research. Provide three bullet points that justify your recommendation.
	Reading	“The Pirates of Illiopolis”, <i>Orion</i> (Sandra Steingraber) ¹⁸
	lectures	Poly vinyl chloride chemistry and manufacture (LV)
2: Gold Nanoshells	activity	Evaluate the data on PVC precursors in the EPA’s Toxic Release Inventory. Using this data and the National Society of Professional Engineer’s statement on ethics, identify the endpoint in a product life cycle for engineers’ responsibility for the safety and welfare of the public.
	Reading	“Science, Sustainability, and the Human Prospect,” <i>Science</i> (Peter H. Raven) ¹⁹ “Nanoshells: Gifts in a gold wrapper,” <i>Nature Materials 2</i> (Mark L. Brongersma) ²⁰
	lectures	Gold nanoshells for cancer (LV); Cell life and death and the influence of heat (MR)
	activity	Based on the data of cell protein activity versus temperature and mass analysis of human cells, compute the approximate thermal energy range needed per volume to kill cancerous tissue.
	Reading	“Immunotargeted Nanoshells,” <i>Science</i> (Loo, Lowery, Halas) ²¹ “Nanotechnology takes aim at cancer,” <i>Science</i> (Robert F. Service) ²²
	lectures	Synthesis, process of gold-coated nanoshells (KC); cancer pathology (MR)
3. Tissue Engineer	activity	Based on the absorption efficiency data, compute the approximate energy of the near infra-red radiation that a patient would need to be exposed to in order to kill a cancer cell with gold-coated nanoshells.
	Reading	Hepatic Tissue Engineering (Chan, Berthiaume, Nath, Tilles, Toner, and Yarmush) ²³ Scaffolds for Tissue Fabrication (Peter X. Ma) ²⁴
	lectures	Microfabrication techniques for tissue scaffolding (RS); liver function (MR);

		Artificial Implantable Liver devices (LV)
	<i>activity</i>	Based on the hepatocyte cell dimensions, microblood vessel dimensions and artificial liver design constraints listed in the reading, design an implantable tissue scaffolding for an artificial liver using planar microfabrication technology.
4. Microfluidic glucose sensor	<i>Reading</i>	“A new monolithic microbiosensor for whole blood analysis,” <i>Sensors and Actuators</i> (J-H. Kim <i>et al.</i>) ²⁵
	<i>lectures</i>	Glucose, insulin regulation in the digestive system (Lars Tomanek); Amperometric sensors (LS); Type II diabetes pathology (MR)
	<i>activity</i>	Based on Center for Disease Control data on trends in early onset of Type II diabetes and federal budget data, identify a source of displaced funding and develop a strategy for increasing the public health and welfare around Type II diabetes and its effects.
5. Debates	<i>Topic 1</i>	RESOLVED: Health care products containing nanocrystalline particles should be allowed on the market before toxicology studies of the nanocrystalline particles.
	<i>Topic 2</i>	RESOLVED: Public funds should be expended for nanotechnology/biotechnology development even though access to treatment by lower-income sectors is less than high-income sectors
	<i>Topic 3</i>	RESOLVED: New technologies should be developed regardless of the potential uses these technologies may have so that the United States can maintain their technological advantage.

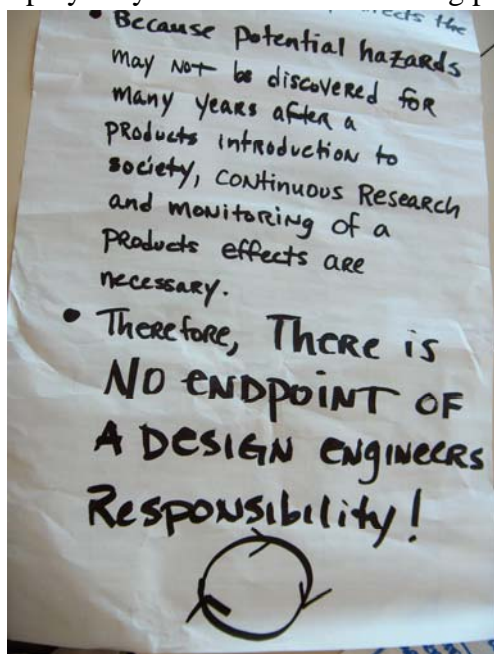
Results of IP+5 to Date: High-energy classrooms



At the time of this writing, we are about three quarters through our pilot offering of this course with 36 students (lead by LV, MR and BS). Figure 4 depicts a typical classroom in which students interact in their groups on the activities. The time spent on “listening” to lectures is minimized. The bulk of the class time is spent addressing a particular question in their teams. For example, at the end of Module 1, we had the students read the *National Society of Professional Engineer’s* statement on ethics. They were then charged with the task of identifying the endpoint for engineers’ responsibility for the safety and welfare of the public in a product life cycle. The groups were given this task after reading a case study on events surrounding an incident at a poly vinyl chloride manufacturing plant.



Figure 4. The IP+5 classroom. Students spend the majority of the 2-hour class in lively discussions about design approaches for NST devices or ethical and society implications of NSEE



Each group summarized their decision and its rationale on a large piece of paper and posted the paper at the end of the class session. The photo to the left is an example of one team’s answer. Their answers, like this one, indicate that the exercises are enabling them to see their role as an engineer as one of responsibility beyond the narrow scope of technical performance of a product.

Each activity requires that the team come up with a specific solution. In the process of deciding on the solution, individuals within the team must listen to the ideas of others and articulate their own ideas. We observe students actively engaged as they debate ideas with one another.

In short, we have witnessed: a) students taking more responsibility for their own learning; b) a high level of involvement by each student in the group activities; c) a high level of inquiry during mini-lectures; d) a high level of student enthusiasm toward the class, with students going out of their way to comment positively on the course design; and e) an increased level of confidence in students’ intellectual abilities. Some of these observations are supported by the mid-point survey responses (presented below), while others come from the instructors’ comparison of the course to other courses they have taught using traditional teaching formats.

¹ Michaelsen.

² Goodman Research Group, Inc., “Executive Summary,” *The Women’s Experiences in College Engineering Project* (Cambridge, MA): xi.

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- ³ Ambrose, S., B. Lazarus, and I. Nair, "No Universal Constants: Journeys of Women in Engineering and Computer Science," *J. Engineering Education* 87 (1998): 365.
- ⁴ *ASEE Profiles of Engineering and Engineering Technology Colleges*, 2004 edition, (Washington, D.C.: American Society of Engineering Educators, 2005): 14.
- ⁵ Drexler, K., "Machine-Phase Nanotechnology," *Scientific American* (September 2001): 74-75.
- ⁶ Schwartz, P.V., D.J. Lavrich, and G. Scoles, "Overlayers of Long Chain Organic Molecules Physisorbed on the Surface of Self-Assembled Monolayers of Alkylthiols on Au(111)" *Langmuir* 19 (2003): 4969.
- ⁷ Schwartz, P.V., "Molecular Transport from an AFM tip: a Comparative Study of Dip-Pen Nanolithography," *Langmuir* 18 (2002): 4041.
- ⁸ Springer, L., M.E. Stanne, and S.S. Donovan, "Effects of Small-Group Learning on Undergraduates in Science, Mathematics, Engineering, and Technology: A Meta-Analysis," *Review of Educational Research* 69 (1999): 1-21.
- ⁹ Bolbeck, C.L., S.E. Campbell, and S.A. Bjorklund, "Grouping in the Dark," *J. Higher Education* 71 (2000): 1-16.
- ¹⁰ Bloom, B.S., M.D. Englehart, E.J. Furst, W.H. Hill, and D.R. Krathwohl, *Taxonomy of Educational Objectives: Handbook 1: Cognitive Domain*. New York: Longman, 1956.
- ¹¹ Hutchison, M.A., D.K. Follman, M. Sumpster, G.M. Bodner, "Factors Influencing the Self-Efficacy Beliefs of First-Year Engineering Students," *J. Engineering Educ.* (2006): 39-47.
- ¹² Bandura, Albert, *Social Foundations of Thought and Action: A Social Cognitive Theory* (New Jersey: Prentice Hall, 1986).
- ¹³ Park, Robert L., "Voodoo Science: The Seven Warning Signs of Bogus Science," *Chronicle of Higher Ed.* 49(21) B20 (Jan 31, 2003).
- ¹⁴ Merkle, R., "Self Replicating Systems and Molecular Manufacturing," www.zyvex.com/nanotech/selfRepJBIS.html (last accessed on May 1, 2006).
- ¹⁵ Stix, G., "Little Big Science", *Scientific American* (September 2001): 32-37.
- ¹⁶ Drexler, K., "Machine-Phase Nanotechnology," *Scientific American* (September 2001): 74-75.
- ¹⁷ Smalley, R., "Of Chemistry, Love and Nanobots," *Scientific American* (September 2001): 76-77.
- ¹⁸ Steingraber, S., "The Pirates of Illiopolis," *Orion* vol 24, #3 (May/June 2005): 16-27.
- ¹⁹ Raven, P., "Science, Sustainability, and the Human Prospect," *Science* 297 (August 9, 2002): 954-958.
- ²⁰ Brongersma, M., "Nanoshells: Gifts in a gold wrapper," *Nature Materials* 2 (May 2003): 269-297.
- ²¹ Loo, C., A. Lowery, N. Halas, J. West, and R. Drezek, "Immunotargeted Nanoshells for Integrated Cancer Imaging and Therapy," *Nano Letters* 5,4 (2005): 709-711.
- ²² Service, R., "Nanotechnology Takes Aim at Cancer," *Science* 310 (November 18, 2005): 1132-1134.
- ²³ Chan, C., F. Berthiaume, B. Nath, A. Tilles, M. Toner, and M. Yarmush, "Hepatic Tissue Engineering for Adjunct and Temporary Liver Support: Critical Technologies," *Liver Transplantation* 10,11 (November 2004): 1331-1342.
- ²⁴ Ma, P., "Scaffolds for tissue fabrication," *Materials Today* (May 2004): 30-40.
- ²⁵ Kim, J-H, B-G. Kim, J-B. Yoon, E. Yoon, C-H. Han, "A new monolithic microbiosensor for whole blood analysis," *Sensors and Actuators A*, 95 (2002): 108-113.