AC 2008-1914: DEVELOPMENT OF A RESEARCH-INTENSIVE, MULTIDISCIPLINARY MINOR IN NANOTECHNOLOGY STUDIES (NTS)

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An Interdisciplinary, Research-Intensive Minor in Nanotechnology Studies

Abstract:

At Stony Brook University, we have developed a multidisciplinary minor in Nanotechnology Studies unique in its ability to attract undergraduate students from a broad range of academic backgrounds, to integrate into existing majors and programs through mentored research, and to foster professional development through teamwork, communications and active learning. The Minor in Nanotechnology Studies (NTS) is an interdisciplinary, research-intensive program intended for students in majors from the College of Engineering and Applied Sciences or the College of Arts and Sciences at who wish to learn about the emerging field of nanotechnology. The coursework in the Minor provides a broad background in the science, design, manufacture, and societal, health and environmental impacts of nanomaterials and nanoscale structures and their applications in engineering and health related areas. The inclusion of a minimum of two semesters of research in the students' own major areas, as well as choice of technical electives, will allow for integration into current interests and disciplines, and will provide knowledge and skills valuable to students planning to seek employment or graduate studies in fields related to the engineering, business, policy or broader impact of nanotechnology.

Background:

a. Need for the minor

In both education and industry it has become clear that nanotechnology does not represent a "stand-alone" activity or field of study – it is an understanding of the impact of unique mechanisms, science and structures at the nanoscale on research and development in traditional fields, such as materials science, mechanical engineering, electronics, biomedical technology, environmental engineering and manufacturing. As such, nanotechnology cannot be taught as a "stand-alone" subject, isolated from its application in design of devices and systems – instead, it must be introduced in the context of research and problem solving in traditional as well as emerging engineering fields suited to student interest. Likewise, it is essential to provide a social, economic and ethical context to application of nanotechnology in manufacturing, medicine, and other contextual areas driving research and development. This provides a unique challenge and requires an approach which successfully integrates nanotechnology into current academic programs. Such an approach has the added benefit of enhancing student engagement and motivation. The result will be a better educated population of engineers, with an appreciation for the critical importance of nanoscale approaches to solving societal problems.

b. Value of active/problem-based approach

There are many references regarding the value of problem-based, active learning environments for improvement of student comprehension and engagement.[1,2,3] Active-learning requires students to be involved in key activities of analysis, synthesis and evaluation.[4] For university students, these activities are most clearly present in the context of directed and independent research.[5] While certain active-learning activities can (and should) be built into the structure of what would normally be a lecture class (such as group discussions, demonstrations, and group design projects), the level of student engagement supported by a research project would be hard to duplicate in a classroom environment. Hence it is essential that a core part of a nanotechnology studies program be independent research courses. In addition to published studies on the value of incorporating research into the undergraduate curriculum, design of our program has been guided by institutional experiences which have demonstrated the value of integration of research experiences into undergraduate programs. Past programs at SBU explored a half dozen different models for incorporating research skill building and opportunities for research into the structure of accredited engineering programs in engineering science, mechanical engineering, electrical engineering, biomedical engineering and computer science. In particular, it was found that allowing use of a mentored research experience as a possible choice for a required technical elective provided a range of research experiences which would be difficult to achieve through a lecture or a laboratory course.

c. Other programs

Models for integration of nanotechnology education into the undergraduate curriculum have been discussed by a number of engineering educators over the past decade, and all have emphasized the need for a multi-disciplinary, active learning and problem based approach.[6] Uddin and Chowdhury specifically concluded that development of a broad-based introductory course at the freshman/sophomore level, which includes general concepts and societal/ethical issues, is essential.[7] They also identified a capstone, design-oriented course as critical to development of an engineering curriculum incorporating an interactive learning approach to nanotechnology. Roco identified key issues for nanotechnology education, including using a system approach to nanotechnology education applicable at all levels, which incorporates interdisciplinarity, integration of research and education, development of freshman/sophomore overview courses, and integration with existing undergraduate engineering curricula.[8] Lee emphasized the need for an interdisciplinary, upper level, active learning-based capstone experience to complement an introductory level course.[9] He specifically cited the need for hands-on activities incorporating visualization and design strategies within such a program. More recent studies have addressed development of specific activities for use within these courses and programs. Many of these specific lessons, activities and kits are available through NSF-sponsored centers which developed them. For example, the Interdisciplinary Education Group of the Materials Research Science and Engineering Center (MRSEC) on Nanostructured Materials and Interfaces at the University of Wisconsin-Madison have developed a large collection of materials which are available online, including kits, videos and laboratory manuals most of which is suitable for use in undergraduate coursework.[10]

While these studies suggested useful innovations to the curriculum and identified pilot coursework at a number of universities, few studies have been published on the outcomes of programs which have been established, providing data by which to judge overall effectiveness. Data on individual courses provide some insight into the value of incorporating pedagogical improvements focused on enhancing student engagement. In 2004, Hersam, et al., reported on development of an interdisciplinary group learning and peer assessment approach to nanotechnology education.[11] The authors designed an upper level undergraduate course which included group activities that used a combination of collaborative, interdisciplinary and problem-based group work in which students engaged in substantial and meaningful peer assessment. Incorporation of these activities appeared to result in overall high grades in the particular course, and overall student comments were very positive. An independent evaluator discussed the course with the students and determined that the approach was valuable in enhancing their overall learning experience, including their belief in their own ability to comprehend complex concepts.

The need to discuss the societal implications of nanotechnology (risk/benefit analysis, economic impacts, ethics and public perception) within a broad-based educational context have been discussed in a number of recent publications.[12,13] Of course, the issue of exactly what constitutes "societal and ethical implications" of nanotechnology is still evolving, as has been pointed out by a number of studies in education and philosophy.[14,15] For example, such issues can also include traditional safety concerns which would be discussed in the context of manufacturability, legal issues involving intellectual property, regulatory and environmental impact, and the emerging field of nanotoxicology. Hence, incorporation of this discussion into an undergraduate course or program would require input from professionals in many fields which are on the forefront of not only nanotechnology development, but also areas such as ethics, risk analysis and nanotoxiciology. Only through incorporation of a variety of current and evolving views into the classroom discussion can students develop the insight necessary to continue their own life-long education in the societal impact of evolving technology.

This type of approach to development of undergraduate courses or programs, in particular broad-based lower division courses, which incorporate a meaningful dialog on societal or ethical issues in nanotechnology have not been as widely reported on (either in terms of design or impact) as purely technical coursework. Hence, it is very important to use novel approaches for designing integrated courses or lessons that have been shown to be successful. Recently, the NSF-supported SENCER program has developed a range of innovative models that incorporate societal and civic issues into traditional science and technology coursework. Science Education for New Civic Engagements and Responsibilities (SENCER) was initiated in 2001 under the National Science Foundation's CCLI national dissemination track. Since then, a large number of courses have been developed, deployed and evaluated which use STEM pedagogical techniques coupled with problems of civic consequence to enhance education. One of the authors, Halada, attended the 2006 summer SENCER workshop, and since then has developed several courses using the SENCER approach, including first year survey courses involving applications of nanotechnology.[17] Another of the authors (Ferguson) has led a number of workshops at SENCER meetings to assist faculty in development of courses. The outcomes and effectiveness of many SENCER courses (including some taught at SBU) have been evaluated using the Student Assessment of Learning Gains (SALG) on line tool initially developed by Elaine Seymour for the NSF-sponsored National Institute for Science Education.[16] Though initially designed for use with chemistry courses, SALG has been modified for instructors from all disciplines who wish to learn more about how students evaluate various course elements in terms of how much they have gained from them. Feedback from the instrument can guide instructors in modifying their courses to enhance student learning. It may be used at any point during a course (for formative feedback) as well as at the end. SALG has a unique "open source" structure which has allowed for use and modification by dozens of institutions of higher education. Hence participants in the program developed at SBU will be encouraged to employ SALG and similar "assessment of learning" tools.

Program development

a. Key elements

Initial program development activities commenced in September, 2007, with a kick-off meeting of the principle investigators for the NUE program and notification to the outside evaluator and the external advisory board. In developing this program, we have taken advantage of current published pedagogical research, the experience of the senior personnel involved in the program, and leveraging of established programs and collaborations to provide a meaningful interdisciplinary academic experience incorporating research and professional development. The foundation of this proposal is a structured Minor in Nanotechnology Studies which includes a clear pathway to recruitment of students, strong strategies for

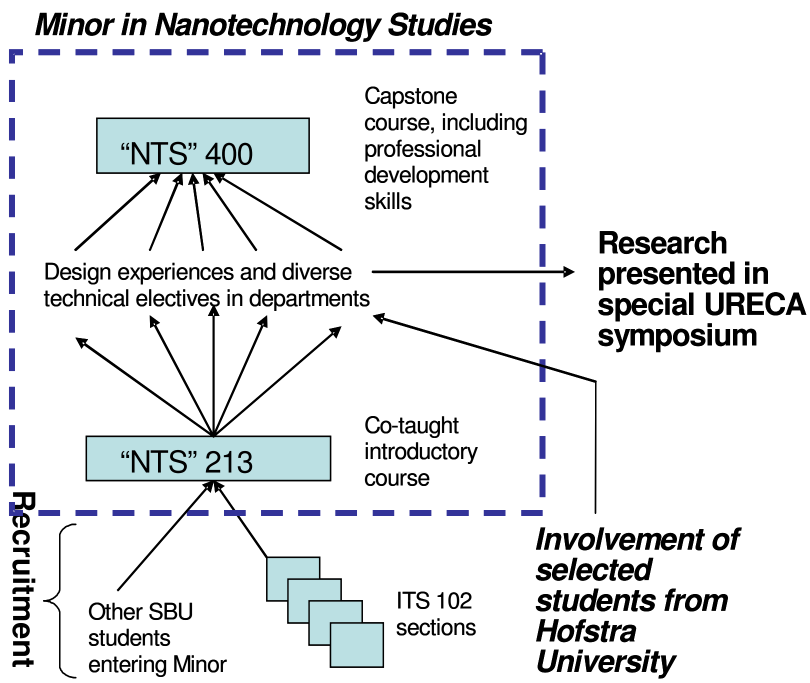

Figure 1: Schematic of interdisciplinary minor in nanotechnology studies (NTS)

learning development, and appropriate mechanisms for assessment and evaluation.

The structure of the minor is unique in that it provides four key elements for success: strong recruitment potential, an interdisciplinary base, research and professional development activities, and full integration into the existing majors and programs in engineering.

Our approach to program development consists of the following key elements:

- Course, program and faculty development (including a faculty workshop) which leverages the experience of NSF-sponsored and other education programs, such as SENCER.

Two courses have been developed as a core component of the Nanotechnology Studies (NTS) minor (figure 1). The first, "**NTS" 213**, will be a multi-disciplinary introductory course (3 credit hours per week), with special attention paid to systems applications. It is a broad-based, co-taught course with lectures from faculty in four engineering Departments. For the purposes of this report, we use the designator "**NTS**". In actuality, the course is cross-listed across four departments: Materials Science (which uses the ESG (Engineering Science) designator), Biomedical Engineering (BME), Mechanical Engineering (MEC) and Technology and Society (EST). Hence the course actually appears as ESG 213; BME 213; MEC 213 and EST 213. This allows students to register with their choice of course designator, and also allows for proper attribution of university enrollment and credit to all four departments, representing the four program coordinators.

Key elements of this course include:

1. Lectures on ethics, nanotoxicology, and the economic and business implications of emerging nanotechnologies. Guest lecturers from the relevant departments and programs at the university will be involved in these specific lectures and associated activities.
2. Guest lectures from outside professional scientists and engineers will be incorporated to provide examples of real-world applications.
3. Hands-on activities and demonstrations to better engage students, to include both those already developed and published, as well as activities developed by our faculty and which incorporate key features identified in published pedagogical research for engagement of students in nanotechnology. This would include modules currently being developed which allow students to see bio-inspired nanomaterial structures using the electron microscopy facility, as well as a gas fuel cell experiment developed to demonstrate the effect of enhancing catalyst surface area on power generation.[17] The in class design projects will be conducted using a studio approach, reported on by Foulds, *et al.*, in which student groups work independently on classroom projects with instructor and teaching assistant supervision and input while encouraged to interact and discuss problem-solving strategies.[18] This approach has been reported to encourage student inquiry and promote motivation in engineering coursework.
4. To reinforce this interdisciplinary approach, the course will feature a semester-long group project. The project will require students to research and present to the class on one particular application of nanotechnology, as well as the social, ethical and business implications of that application. Initial topics will include nanotechnology in medicine, transportation infrastructure, energy, agriculture/food processing, drugs and cosmetics, and environmental cleanup.

It is also anticipated that this course will be held in conjunction with the upper level course, "**NTS" 400** (4 credit hours per week). As described above, this is a cross-listed course, designated as ESG400, BME 400, MEC 400 and EST 400, for the reasons described earlier. It has been designed as a multi-disciplinary capstone course in which students present their research experiences, and which will also meet with the introductory course several times so that incoming students can observe the results of peer-driven research. Key elements of this course include:

1. Training as mentors for the freshman/sophomore projects, providing peer advisement and feedback.
2. A structure that provides a forum for students to learn professional development skills (including advanced presentation, proposal writing, and scientific publication skills), assist in the mentoring process, and network with members of the professional scientific and industrial communities. These activities will help to further develop the research projects students have been involved in as part of the minor program, and will provide strong preparation for successful careers in science and engineering. As part of this effort, students will prepare a journal quality manuscript on their work and a NSF graduate fellowship type grant proposal.
3. Incorporating elements of a final "capstone" nanotechnology design class which could dovetail with existing engineering senior design programs.

- Incorporation of independent research into the structure of the NTS Minor, leveraging the University's extensive research infrastructure.

Every student in the NTS Minor will be required to complete at least **6 credit hours of independent research coursework** (often given a designator of 499) in their own Major program. We will tie nanotechnology to each student's interests and learning goals through incorporation of these key features:

1. Each student will have two advisors – one from the lab in which they are working, and a second who is one of the coordinators of the minor who represents a different area.
2. Students would earn credits through targeted research experiences, if possible in their home departments. This means that students will be able to use some, if not all of these credits towards completion of their degree requirements. A common problem has been the inability of students in credit-intensive engineering programs to be able to add more than one or two courses to their program, even if attaining a minor is a result. This has made recruitment to new minors and programs to be extremely difficult. Participation of students from engineering majors in the NTS minor would only require the addition of perhaps seven credits to the standard program requirements, leading to successful integration of nanotechnology studies into undergraduate degree programs.
3. Students would be required to meet together periodically to discuss their research – at least twice per semester, a meeting would be held in the evening for students to gather to discuss research with the minor coordinators.
4. We have been developing a list of particular labs who would welcome involvement from undergraduates. The laboratories and associated faculty have worked with undergraduates in the past, and these students have gone on to successful positions in research and industry. To encourage faculty participation, some support for student involvement in laboratory research in the form of a budget for supplies, will be provided. Support will also be available for student travel to regional and national conferences to present their research in selected cases.

5. In addition, research opportunities would exist with the new national Center for Functional Nanomaterials (CFN) at nearby Brookhaven National Laboratory. A representative from CFN will serve on the Program Advisory Board.

In addition to these 3-4 courses (NTS 213/6 research credits/NTS 400), students would be required to take at least two technical electives which could be identified from among current University offerings in students' home departments. This would allow for additional enhanced integration into each students current major.

- Support for student research experiences which includes leveraging of existing and highly successful programs at Stony Brook University.

The university has an infrastructure already in place to encourage, support and administer undergraduate research. In 1987, it was one of the first research universities nationwide to establish an Office for Undergraduate Research and Creative Activities (URECA) for the specific purpose of promoting undergraduate research. URECA hosts annual events to showcase student work, informs students about opportunities in research and creativity, administers undergraduate research programs, and publishes an annual collection of undergraduate abstracts. We will hold an annual undergraduate nanotechnology research symposium each year in conjunction with the extremely successful URECA annual research event. Participation is mandatory for students in the NTS minor. The director of URECA will be a member of our Program Advisory Board.

- **Outreach to Hofstra University**, a nearby private four-year university with a strong engineering program but few opportunities for nanotechnology-related research.

Through ongoing collaborations with Prof. M.D. Burghardt at Hofstra University (approximately 45 minutes from the Stony Brook University campus), we have established a pilot program with summer research opportunities for about six undergraduate students from the engineering programs at Hofstra. These students will work alongside students in the NTS minor in the laboratories at Stony Brook, and can earn research credits that can transfer to their home institution. In addition, faculty from Hofstra University will be invited to participate in the faculty development workshop at SBU.

- Identification of at least **4 Information and Technology Studies (ITS) seminars** (1 credit) in the Spring of the first year which can act as an introduction (and **recruitment tool**) to the Minor.

The Undergraduate College for Information and Technology Studies (ITS) is a first year learning community college associated with a group of residence halls and has a large percentage of engineering-oriented students. The overall student population of ITS currently stands at about 450 who enter in the Fall semester. The selected sections will provide an introduction for about 80 students to some aspects of nanotechnology using a SENCER-inspired pedagogy – an example would be an introduction to medical applications of nanotechnology with a special section on medical ethics and how the medical profession is approaching nanoethics. These courses offer a very low-level, non-mathematical introduction and will provide a way to advertise and recruit students from multiple disciplines to the minor. The titles of the four sections designed to act as an introduction for the NTS minor are: "Nanotechnology: Fact and Fiction";

- A **Program Advisory Board**, composed of both University and outside members, will be created to assist in program development and evaluation activities.

The advisory board will be invited to the undergraduate research symposium held in conjunction with the URECA exposition in April. They will also be provided with a summary of the years activities and a synopsis of the program evaluation. Their input will be sought in further development, expansion and optimization of the program.

b. Students directly impacted:

Approximately 80 students will be introduced to nanotechnology topics in each year in the 4 ITS seminar sections (Table 2). We anticipate 30 students to participate in the introductory course in the first year of the program, with an expansion to 40 - 60 students in the second year. At least 60 students should be part of the minor by the second year, either registered for the two courses or performing research for the minor. As mentioned above, a pilot program with Hofstra University will bring a small group of students, at least 6 additional students, to research activities each year. These overall numbers of students involved in aspects of this program are summarized in the table below.

Table 2: Planned direct student impact from the proposed program

Year	Students in ITS 102 sections	Students in NTS 213	Students in Research in minor	Students in NTS 400	Hofstra students	**Total students:**
1	80 (current)	22 (current)	20	0	6	**128**
2	80	50	20	20	6	**176**

Underrepresented groups, including students from minority and economically disadvantaged groups and female students, will be recruited to the program through the existing strong infrastructure for supporting diversity in science, technology, engineering, and mathematics (STEM) at Stony Brook University. Existing programs at the University which will be approached as part of our outreach efforts include Women in Science and Engineering (WISE); Collegiate Science and Technology Program (CSTEP), funded by the New York State Education Department; SUNY Louis Stokes Alliance for Minority Participation (SUNY LSAMP)**;** and the Science and Technology Entry Program (STEP). Materials describing the NTS minor will be developed for distribution to students in these programs, and, where possible, presentations on the minor will be conducted at events held in association with these organizations. Our initial student group currently registered for the 213 course includes about 18% female students and a similar percentage drawn from underrepresented groups. One of our goals for the coming year will be to increase these percentages through interactions with the programs mentioned above.

c. Evaluation Plan:

The responsibilities for program evaluation will be shared. Professors and others responsible for student learning will be in the best position to assess student academic performance and the level of success of research projects. Program administrators and faculty will judge whether new courses meet their goals.
The external evaluator will study implementation of the program, that is, how resources are used to develop and initiate activities and how activities are implemented. In its first phase the evaluation will consider the experiences of faculty, students and administrators: their engagement, motivation, interest, and performance of the various program activities. Most important in this regard will be implementation of the two courses planned, and research projects. Evaluation methods will include the use of site visits with observations and interviews, surveys to obtain data about student involvement in program activities, focus groups, phone interviews, analysis of data, review of relevant documents and literature, and report preparation. As the project develops, the evaluation will verify and analyze outcomes—planned and unplanned. Some outcomes will correspond to the project goals. But all projects produce unexpected outcomes and the evaluation will be open to these since they can be important in considering the project's impact and direction.

The table below shows the connections between the project and evaluation activities. In this project there is not a one-to-one correspondence between goals and activities. Rather, the new courses and mentored research will, working in coordination with one another and with existing programs and courses, provide the desired outcomes, achieving the project's goals.

Table 3: Project Evaluation Matrix

<table>
<tr><th>Project Goal Areas</th><th>Project Activities</th><th>External Evaluation Activities</th><th>Indicators of Success</th></tr>
<tr><td rowspan="2">Understanding of nanoscience and applied nanotechnology.</td><td rowspan="4">1. Multi-disciplinary introductory course, co-taught with hands-on activities.
2. Mentored research experiences, six credits in different departments.
3. Multi-disciplinary capstone course.</td><td rowspan="4">Site visits with observations, focus groups and interviews.
Phone interviews of faculty and program administrators.
Surveys to assess student experiences with research, career interests, grasp of nanotechnology issues.</td><td>Courses successfully implemented</td></tr>
<tr><td>Student enrollment; academic success and satisfaction</td></tr>
<tr><td>Interest and motivation</td><td>Reported interest and motivation</td></tr>
<tr><td>Multi-disciplinary experiences; appreciation of the scientific community;</td><td>Engagement in research; quality of research projects.</td></tr>
</table>

Understanding of nanotechnology issues		On-going discussion with program administrators.	Fluency in discussing issues.

d. Dissemination of Results:

Results of this program will be disseminated through Journal Articles and conference presentations at the American Association for Engineering Education annual conference. In addition, the proposed program includes a symposium on student research projects, to be held in conjunction with the annual URECA conference on undergraduate creative activities and research at SBU. A faculty workshop will be held in the Fall to disseminate information on teaching of nanotechnology topics as well as pedagogical mechanisms for improving student learning. This half day workshop will also be used to advise and train the ITS 102 faculty involved in this program, to discuss program activities with the Program Advisory Board, and to plan new teaching and dissemination activities.

The success of our dissemination efforts will be evaluated through a review of the proceedings of the symposium, as well as through surveys of the impact and effectiveness of the faculty workshop. Along with the annual conference presentation and publications in engineering education journals, this material will be reviewed at the annual meeting of the program coordinators with the Program Advisory Board and with the program outside evaluator.

e. Preliminary results:

As the program has only been very recently approved as a minor in the College of Engineering and Applied Sciences (December 2007), there is little performance data to report on at the time this manuscript was assembled. Feedback from the first co-taught course, Introduction to Nanotechnology Studies, will be available at the time of presentation at the 2008 ASEE annual meeting. However, in addition to the views presented during the program and course approval process, it is of interest to note the diversity represented by the backgrounds of the students who have already registered for the first offering of the introductory course (as well as the general enthusiasm of these students). The first 22 students to register represent a remarkable 11 majors (plus 3 who are listed as “general/undecided). These include: Engineering Science (4), Electrical Engineering (3), Biomedical Engineering (4), Biology (3), Business, History, Technology and Society, Applied Mathematics and Statistics, Astronomy/Planetary Sciences, and Pre-Music (one each). Students from several other disciplines in both the College of Engineering and Applied Sciences (Mechanical Engineering) and the College of Arts and Sciences (Physics) have also expressed an interest in registering for the minor.

At the ASEE annual meeting, we will also be able to present data from the first report from the external advisory board, as well as information gathered by the program’s external evaluator. We will also have completed selection of students for summer research projects. A number of these projects will be described at the meeting, along with background on undergraduates selected for the research (both from Stony Brook University and Hofstra University).

Conclusions

As of the writing of this report, the proposal to the College of Engineering and Applied Sciences College Teaching and Protocol Committee (which is charged with approving new minors and courses) has approved establishment of both the 213 and 400 courses as cross-listed multidisciplinary courses, as well as establishment of the minor itself. As a result, the courses and the minor are now a permanent part of the curriculum of the College of Engineering and Applied Sciences. Additional results and feedback will be available (and will be presented) at the time of the ASEE national meeting. The feedback loop will be fully established and operational, program improvements will be developed based upon informed data from evaluations, and the impact of the program on student learning in the area of nanotechnology will be assessed.

In summary, we have developed a program with the following Key Education Goals and Objectives:

- Learning comprehension in basic principles of nanoscience and nanoscale engineering
- Understanding applications of nanotechnology to engineering and medical systems
- Student engagement and motivation
- Interdisciplinary experience and teaming
- Generating a supportive, integrated learning community -- a mirror of the "community of scientists" which provides the structure for scientific advancement.
- Development of an appreciation for life-long learning
- A global understanding of the impacts and issues regarding nanotechnology and applications

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