City College of New York
Nanoscale Undergraduate Education
Evaluation Report
2008-2009

October 2009

Prepared by:

Elisabeth A. Palmer, Ph.D.
ASPEN Associates, Inc.

City College of New York
Nanoscale Undergraduate Education
Evaluation Report
2008-2009

Executive Summary

Background

During the 2008-2009 school year, the CCNY-NUE project conducted a second field test of its nanomaterials course (CHE 59808), the accompanying nanomaterials laboratory course (CHE 59806), and the "nano nuggets" module in ENGR 101. The second field test replicated the first field test in 2007-2008 in the scope of implementation. The nanomaterials lecture course and subsequent laboratory course were designed as a series of experiences intended to prepare students to conduct research with faculty. The nano nuggets module was a short, 5-week experience intended to expose students to nanotechnology to increase interest and create a pipeline into more formal coursework. This report summarizes the impact of the course materials on teaching, learning, and student engagement.

Key Findings

Nano Nuggets (ENGR 101)

Nano nuggets was offered as a five-week module students could select within the ENGR 101 course. A total of 99 students enrolled in the nano module during the first field test; in the second field test, when the module was offered twice — once in the fall and once in the spring — 189 students enrolled.

The nano nuggets module was one of the modules that received favorable overall ratings with regard to quality, utility, and interest. The nano module was rated as having effective pedagogy, materials, and equipment. It was also rated as "interesting" and "challenging". Overall, students rated the nano nuggets module as "worthwhile."

Nanomaterials Lecture Course (CHE 59808)

This introductory survey course was offered in fall 2007 and fall 2008. Twelve students completed the course the first year; 27 completed it the second year. Most of the enrolled students were majoring in chemical engineering.

Interest in Nanotechnology

In both field tests, all of the students' enrolled in the nanomaterials course expressed an interest in nanotechnology from the very beginning of the course, which did not wane over time. All or almost all of the students felt it was useful to learn about nanotechnology with most agreeing that "nanotechnology is the technology of the future." Student's interest in nanotechnology was also reflected in the fact that most were interested in doing undergraduate research in nanotechnology and would consider a career in nanotechnology.

Knowledge of Nanotechnology

In the first field test, students in the nanomaterials lecture course appeared to have a general knowledge of nanotechnology prior to enrolling in the course. By the end of the course, they demonstrated an increased understanding of knowledge specific to nanotechnology on 6 of the 16 questions. This increased understanding was noted in the following content areas:

- methods of synthesizing nanoparticles
- configurations of carbon nanotubes
- nanoparticles as additives in polymers
- self-assembly in nature
- examples of nanotechnology inventions
- examples of nanomaterials

In the second field test, students in the nanomaterials lecture course did not come in with a general knowledge of nanotechnology but obtained it. By the end of the course, they also demonstrated an increased understanding of knowledge specific to nanotechnology on 13 of the 16 questions. This increased understanding was noted in the following content areas:

- methods of synthesizing nanoparticles
- configurations of carbon nanotubes
- mechanical properties of nanoparticles
- optical properties of nanoparticles
- nanoparticles as additives in polymers
- imaging of nanoparticles
- ethnical concerns and regulations
- examples of nanotechnology inventions
- examples of nanomaterials

Course Quality and Utility

In both field tests, students rated the nanomaterials lecture course as offering content, pedagogy, instructional materials, and support that came together to provide an environment conducive to learning.

Students also reported that their knowledge of specific nanomaterials and nanotechnology concepts and principles, related skills, and understanding of ethical and contemporary issues related to nanotechnology had increased as a result of their participation in the nanomaterials course. Students confirmed what their pre/post assessments indicated in reporting that they are now:

- able to give examples of nanomaterials,
- able to explain terms generally used in nanoscience and nanotechnology,
- familiar with methods of synthesizing nanomaterials,
- familiar with macroscopic phenomena,
- able to predict trends in mechanical properties of nanomaterials, and
- familiar with the operating and limitations of imaging devices (second field test).

Nanomaterials Laboratory Course (CHE 59806)

This hands-on application course was offered in spring 2008 and spring 2009. Nine students completed the course the first year; 9 completed it the second. Most were chemical engineering students and all had completed the introductory nanomaterials lecture course. Working in groups of two or three, students conducted and wrote up findings from five separate experiments that allowed them to apply what they had learned in the nanotechnology course.

Knowledge of Nanotechnology

In both field tests, the total scores for the laboratory reports were high across the groups, averaging more than 80% of the possible 600 points per final report in the first field test and 85% or more in the second:

- Module 1: Chemistry – Synthesis of Nanoparticles (85% and 85%)[1]
- Module 2: Electrical Engineering / Physics – Optical Characteristics of Nanoparticles (91% and 86%)
- Module 3: Chemical Engineering – Imaging of Nanomaterials (94% and 88%)
- Module 4: Mechanical Engineering – Mechanical Properties of Nanoparticle Reinforced Composite Materials (81% and 85%)
- Module 5: Ethical and Societal Considerations for Nanomaterials (89% and 91%)

From the beginning, students were able to write up the introduction and references sections of their laboratory reports. Over time, they also learned more about how to write the results,

[1] Represents percent on first field test and second field test, respectively.

discussion, and conclusion sections, as evidenced by instructor feedback and subsequent revisions.

Course Quality and Utility

Overall, students rated the laboratory course as offering content, pedagogy, instruction and support that provided an environment conducive to learning. Students also agreed that "the instructional materials were complete and helpful."

With regard to the course objectives students also agreed that their knowledge of specific nanomaterials and nanotechnology concepts and principles, related skills, and understanding of ethical and contemporary issues related to nanotechnology increased as a result of their participation in the nanomaterials laboratory course. Specifically, students generally confirmed the acquisition of the skills demonstrated in their laboratory reports:

- synthesizing nanoparticles,
- operating a spectrometer,
- analyzing and interpreting optical data,
- operating an atomic force microscope,
- analyzing and interpreting stress-strain data, and
- a familiarity with ethical issues related to nanomaterials and their applications.

In addition, students reported an increased ability to apply knowledge of mathematics, science and engineering.

Summary

In the first field test, the evaluation data provides evidence that the CCNY-NUE team was successful in developing and implementing nanotechnology coursework, laboratory experiences, and mini-"nano nuggets" modules that engage students and promote learning of knowledge and skills relevant to engineering and to nanotechnology. The second field test validated previous findings in demonstrating for a second time the success of this project:

> Students are learning key nanotechnology theories and concepts and are able to successfully apply that learning in a laboratory setting.

In addition, the evaluation also revealed opportunities to enhance the program to further improve its effectiveness. Specifically, students' would benefit from further developing their scientific skills:

- Students need more guidance on how to conduct experiments, including skills relevant to laboratory work and analyzing and interpreting data.

- Students need more guidance in communicating what they know both verbally and in writing.

For More Information

Ilona Kretzschmar
Associate Professor
Chemical Engineering Department
City College of New York
Steinman Hall, T-312
140th Street and Convent Avenue
New York City, NY 10031
(212) 650-6769
kretzschmar@ccny.cuny.edu

Elisabeth Palmer, Ph.D.
Director of Research / CEO
ASPEN Associates, Inc.
7760 France Avenue South, Ste. 1100
Edina, MN 55435
(952) 837-6243
epalmer@aspenassociates.org

Overview

During the 2008-2009 school year, the CCNY-NUE project conducted a second field test of its nanomaterials course (CHE 59808), the accompanying nanomaterials laboratory course (CHE 59806), and the "nano nuggets" module in ENGR 101. The nanomaterials lecture course and subsequent laboratory course were designed as a series of experiences intended to prepare students to conduct research with faculty. The nano nuggets module was a short, 5-week experience intended to expose students to nanotechnology to increase interest and create a pipeline into more formal coursework. This report presents results from the second field test while drawing conclusions about the effectiveness of the project on the basis of findings from both field tests.

Methods

In light of the intended outcomes from the CCNY-NUE experiences, the 2008-2009 field test gathered data on the impact of the nanomaterials lecture and laboratory courses on teaching and learning, and of both courses and the nano nuggets on student engagement. The evaluation included several data sources: a pre/post assessment of student learning in the nanomaterials course, laboratory reports, course evaluations for both the lecture and laboratory courses, and other feedback from students, teaching assistants, and faculty gathered via interviews, a focus group, and written correspondence.

Course Goal Assessment

The purpose of the Course Goal Assessment was to (1) assess the change in students' knowledge of nanotechnology and (2) interest in nanotechnology as a result of the nanomaterials lecture course (CHE59808). As such, the Course Goal Assessment was administered at the beginning and end of the nanomaterials course as an online survey. The Course Goal Assessment used in the field test included five questions to measure students' general knowledge of nanotechnology, sixteen questions to measure specific knowledge of nanomaterials, five questions to assess students' interest in nanotechnology, and three background/demographic questions.

Laboratory Reports

In the nanomaterials laboratory course (CHE 59806), students applied what they had learned in the nanomaterials lecture course through hands-on experiences. Students conducted four different experiments and a survey related to ethical and societal implications, and wrote a formal report of their group's findings. The reports were graded equally on six components: (1) introduction, (2) experimental design, (3) results, (4) discussion, (5) conclusions, and (6) references. If the initial laboratory report was submitted on time, the group had the option of submitting a revised report based on feedback provided by the instructor. All such revisions had to be submitted before the end of the course; no revisions were allowed for the final laboratory on ethics.

Course Evaluations

Students enrolled in the nanomaterials lecture and laboratory courses completed an end-of-course evaluation. This evaluation, which is regularly administered in all engineering classes, asks for students' opinions about the quality and utility of the course. In addition to asking about the quality of the teaching and instructional materials, each course evaluation asks for feedback on the extent to which course objectives – specific to the course and for the engineering department – were met.

The course evaluation for the nanomaterials course included twelve questions related to the course quality (e.g., rating the materials, instructor) and fourteen questions related to the course objectives (i.e., did students feel they learned specific material) to which students were to respond on a scale of -3 (strongly disagree) to +3 (strongly agree). Similarly, the laboratory course included eleven related to course quality, twelve questions related to course objectives, and two related to interest. All evaluations were administered as a paper-and-pencil survey at the conclusion of each course.

Students who enrolled in the five-week nano nuggets module also completed a shorter end-of-course evaluation. Like the longer course evaluation, this one asked for students' opinions about the quality and utility of the course. The nano nuggets course evaluation included six questions related to quality, three related to interest, and one related to utility.

Other Data Sources

This year's evaluation also included additional feedback from students and teaching assistants, including a focus group with students; a focus group with the teaching assistants; email correspondence between the instructor, students, and teaching assistants and outside parties interested in the project; and usage statistics from the electronic Blackboard.

Key Findings

Nano Nuggets (ENGR 101)

Students enrolled in the ten-week ENGR 101 course explored different engineering topics through a one-hour lecture, two-hour laboratory format. Students could choose from seven different modules that covered topics in electrical engineering, computer science, civil engineering, and nanoscale science. Students could choose to enroll in two, five-week modules or one, ten-week module. Last year, 34 students enrolled in the five-week nano module, which was included as a new offering. This year, 189 students enrolled in the nano module. As shown in Table 1, all seven modules had increased enrollments over the previous year.

Table 1: Enrollment and Course Evaluations for ENGR 101 Modules

	First Field Test					Second Field Test								
	Fall 2007					Fall 2008					Spring 2009			
Module	Average Rating					Average Rating					Average Rating			
	Q	U	I	O	N	Q	U	I	O	N	Q	U	I	O
5-weeks														
Aggregator	1.18	1.03	1.07	1.13	83	0.90	0.81	0.95	0.91	102	1.05	0.97	0.84	0.97
Nano	1.04	0.71	0.78	0.91	34	1.10	1.02	1.07	1.08	126	1.15	1.02	0.94	1.06
10-weeks														
Aggregator	--	--	--	--	--	0.35	0.33	0.43	0.38	20	1.18	1.29	1.29	1.23
Bridge	0.69	0.44	0.67	0.65	48	0.75	0.48	0.76	0.72	94	0.64	0.37	0.51	0.57
Digital Clock	-0.30	-0.17	0.00	-0.19	36	0.38	0.82	0.93	0.61	64	1.49	1.20	1.22	1.37
Electrical	0.99	1.50	1.47	1.21	10	0.78	1.00	1.17	0.93	22	1.40	1.75	1.56	1.49
Robot	--	--	--	--	--	1.26	1.36	1.37	1.31	52	0.89	0.47	3.07	1.57
All Modules	0.72	0.70	0.80	0.74	211	0.79	0.83	0.95	0.85	480	1.11	1.01	1.35	1.18

Notes: Q = quality (5 items), U = utility (1 item), I = interest (3 items), O = overall (9 items).
All items rated on scale of -3 (strongly disagree), -2 (disagree), -1 (disagree a little), 0 (neutral), +1 (agree a little), +2 (agree), +3 (strongly agree)
N= number of students rating the course

Course Evaluation

Students who enrolled in ENGR 101 completed an end-of-course evaluation for each module they selected. This survey gathered student opinions about the quality and utility of the module.

In the first field test, four of the five modules received passing marks:[2] Nano, Aggregator, Bridge, and Electrical Device (the Digital Clock module received poor ratings on all items). Across these four modules, students agreed that the instructor explained the material clearly, that materials were easy to understand, activities could be completed during lab hours, that equipment worked properly, and that the available tools and supplies were adequate (quality rating). When it came to rating the four modules on how interesting and challenging they were, all four received passing marks (interest rating). Students also felt that the Nano, Aggregator, and Electrical Device modules were "worthwhile" (utility rating). The most popular modules during the first field test, as noted by their overall ratings, were: Aggregator, Electrical, and Nano.

In the second field test, seven modules were offered of which all received passing marks.[3] Across the seven modules, students again agreed that the modules were implemented well (quality rating), were interesting and challenging (interest rating), and "worthwhile" (utility rating). The most popular modules during the second field test, as noted by their overall ratings, were: Robot, Electrical, Digital Clock, Aggregator, and Nano.

By the end of the second field test, five of the seven courses, including the Nano module saw improved overall ratings.

---

[2] Average ratings above zero to indicate at least some level of agreement.
[3] Ibid.

Nanomaterials Course (CHE 59808)

Course Description

The nanomaterials lecture course was designed as a “survey course” that would introduce students to the key concepts, materials, and equipment that are most relevant to research on and using nanotechnology within the core fields of engineering (chemical, electrical, and mechanical).

The nanomaterials course included seven different modules. The modules covered (1) synthesis, (2) modeling, (3) linear and non-linear optics, (4) mechanical properties, (5) imaging, (6) applications, and (7) societal impact of nanomaterials. The course included both lecture and homework that required students to write short essays on topics such as nanowire synthesis, self-assembly, company portfolio, societal impact, and imaging technology in preparation for writing their ten-page term paper. In addition, students had to prepare models for carbon nanotubes and apply the modeling software they were introduced to in the course.

Participant Characteristics

Of the 27 students who completed the nanomaterials lecture course, eleven completed the pre/post assessment of knowledge and the end-of-course evaluation. Like the first field test, most of the enrolled students were majoring in Chemical Engineering. In the first field test, half of the students had heard about nanotechnology prior to enrolling in college, having been exposed to the topic in high school; in the second field test it was just over half (55%).

Interest in Nanotechnology

All of the students’ enrolled in the nanomaterials lecture course expressed an interest in nanotechnology from the very beginning of the course, which did not wane over time. As was true in the first field test, almost all of the students felt it was useful to learn about nanotechnology with most agreeing that “nanotechnology is the technology of the future.” Student’s interest in nanotechnology was also reflected in the fact that most were interested in doing undergraduate research in nanotechnology and would consider a career in nanotechnology. At the start of the nanomaterials course, a few students were even interested in writing an article for a campus publication or popular science journal on nanotechnology and remained interested.

Knowledge of Nanotechnology

The pre/post course assessment included both general and specific knowledge of nanotechnology. The general knowledge section included five questions about interdisciplinary nature of nanotechnology and where to go for related resources and funding. Although 40% of the students in the second field test said they had been exposed to nanotechnology in previous college courses, very few were able to answer the general knowledge questions correctly on the pre-test. However, after completing the nanomaterials course all or almost all of the students possessed this general knowledge. This differed from the first field test in which 50% of the students had been exposed to nanotechnology in other college courses and two-thirds came in with this general knowledge, as demonstrated by their pre-test scores.

The pre/post course assessment also included sixteen questions related to specific knowledge of nanoscale science as conveyed in the nanomaterials course. In the first field test, students demonstrated improved understanding on 6 of 16 questions (38%), no change in knowledge from pre- to post-test on 8 of 16 question (50%), and decreased understanding on 2 of 16 questions (12%). In the second field test, students performed better, demonstrating improved understanding on 13 of 16 questions (81%) and no change in knowledge from pre- to post-test on 3 of 16 questions (19%). When there was no change in knowledge from pre- to post-test, about half to two-thirds of the students were able to demonstrate an understanding of this concept at the beginning of the course (i.e., on the pre-test).

The topics in which students demonstrated *increased* understanding included:

- methods of synthesizing nanoparticles (Q1)
- configurations of carbon nanotubes (Q2)
- mechanical properties of nanoparticles (Q3b, Q5a, Q9a, Q9b)
- optical properties of nanoparticles (Q4a, Q4b)
- nanoparticles as additives in polymers (Q5b)
- imaging of nanoparticles (Q6)
- ethnical concerns and regulations (Q8b)
- examples of nanotechnology inventions (Q9c)
- examples of nanomaterials (Q9d)

The topics in which students demonstrated *no change* in understanding included:

- molecular properties that control the state of a material (Q3a)
- self-assembly in nature (Q7)
- ethnical concerns and regulations (Q8a)

That students in the second field test demonstrated many more gains in knowledge than students in the first field test may suggest that the course was implemented with greater fidelity over time.

Course Evaluation

As was true in the first field test, students in the second field test reported that the nanomaterials course had the characteristics of a quality learning environment (see Table 1). Students agreed that the content, pedagogy, instructional materials, and support came together to provide an environment conducive to learning. More specifically, students felt that the expectations for learning were clear, the content was relevant, the instructional methods and materials supported learning, and feedback on their performance and support from the instructor were readily available. Student ratings of the helpfulness of the “textbook” in learning the course material were neutral, as no textbook was utilized. In lieu of a textbook, a set of handouts that included background materials was prepared and made available to students via PowerPoint presentations and an electronic Blackboard.[4] Ratings of course quality in the second field test, although still indicative of a quality course, were somewhat lower than the first field test.

With regard to the course objectives, overall, students also agreed that their knowledge of specific nanomaterials and nanotechnology concepts and principles, related skills, and understanding of ethical and contemporary issues related to nanotechnology increased as a result of their participation in the CHE 59808 nanomaterials course (see Table 2). Specifically, students generally confirmed what their pre/post assessments indicated in that they reported that they are:

- able to give examples of nanomaterials,
- able to explain terms generally used in nanoscience and nanotechnology,
- familiar with methods of synthesizing nanomaterials,
- familiar with macroscopic phenomena,
- able to predict trends in mechanical properties of nanomaterials, and
- familiar with the operating and limitations of imaging devices[5]

Other ratings suggest that the instructional materials course could be somewhat improved, particularly with regard to enhancing students' understanding of the impact of engineering solutions in a global and societal context, their knowledge of contemporary issues, and their ability to communicate effectively.

---

[4] A review of Blackboard usage statistics indicated that students primarily accessed this electronic sharing and communication tool to obtain the course content materials and announcements from the professor. As would be expected, there was a much higher level of activity early on in the course as students became familiar with the course materials. Over time, spikes in access seemed to reflect the start of a new module within the course. Students varied in their use of the Blackboard with some accessing it quite a bit and others less so. Access to the Blackboard occurred throughout the day, but primarily from 8 a.m. to 6 p.m. with the heaviest usage from 5 p.m. to 6 p.m. Students were most likely to use this course support on Fridays and Sundays.

[5] In the first field test, students agreed that they become familiar with imaging procedures in their course evaluations. However, their scores on the assessment did not support this.

Table 1. Mean student ratings of course quality for nanomaterials course (CHE 59808) during first and second field tests, fall 2007 and 2008.

Course Quality	2007-2008 Mean[1] (S.D.)	2008-09 Mean[1] (S.D.)	Effect Size Difference[2]
1. The instructor made clear the important points I had to master for this course.	2.73 (0.65)	2.32 (0.95)	0.51
2. The syllabus was followed (if there was no syllabus, circle -3)	2.64 (0.67)	2.45 (0.91)	0.24
3. The instructor did ***not*** present the material in a way that made it clear what was to be learned and why.	-2.55 (0.69)	-1.41 (1.94)	0.87
4. The relevance of this course to chemical and other areas of engineering was made clear.	2.45 (0.69)	1.86 (1.46)	0.55
5. The instructor was available during office hours, by e-mail, or other means of consultation.	2.91 (0.30)	2.41 (0.91)	0.83
6. The homework was helpful in learning the course material.	2.73 (0.47)	2.09 (1.15)	0.79
7. The instructor made good use of teaching media such as PowerPoint presentations and Blackboard.	2.73 (0.47)	2.59 (0.80)	0.22
8. The course content did ***not*** meet my expectations.	-2.55 (0.69)	-1.86 (1.58)	0.61
9. The course material in both content and techniques was enhanced by well-chosen examples and illustrations.	2.55 (0.52)	2.36 (0.80)	0.29
10. Grading of homework and quizzes was done in a timely manner (courses only). Grading of reports was done in a timely manner (labs and design courses).	2.82 (0.41)	2.18 (1.10)	0.85
11. The instructor ***dis***couraged questions and class discussion.	-2.80 (0.42)	-1.68 (2.15)	0.87
12. The textbook was ***not*** very helpful in learning the course material.	-0.60 (1.27)	-0.76 (2.05)	-0.10

Notes: [1] Ratings measured on a scale of -3 (strongly disagree) to +3 (strongly agree). [2] Effect sizes represent [(mean first field test – mean second field test) / mean s.d. of first and second field tests]. Effect sizes of 0.20 to 0.49 are small; 0.50 to 0.79 are moderate; and 0.80+ are large.

Source: ABET Course Feedback Survey, fall 2007 and fall 2008.

Table 2. Mean student ratings of course and ABET objectives for nanomaterials course (CHE 59808) during first and second field tests, fall 2007 and 2008.

Course Objectives	2007-08 Mean[1] (S.D.)	2008-09 Mean[1] (S.D.)	Effect Size Difference[2]
1. I am able to give examples of nanomaterials and rationalize why they are nanomaterials.	2.64 (0.67)	2.33 (1.35)	0.31
2. I can explain terms generally used in nanoscience and nanotechnology such as quantum dot, scanning probe, nanotubes, etc.	2.55 (0.69)	2.18 (1.05)	0.43
3. I am ***not*** familiar with synthetic routes to nanomaterials.	-2.55 (0.52)	-1.64 (1.92)	0.75
4. I can qualitatively explain familiar macroscopic phenomena such as phase transitions, diffusion and wetting, in terms of molecular motion and interactions.	2.36 (0.81)	1.95 (1.13)	0.42
5. I am ***not*** able to predict trends in the mechanical properties of nanomaterials and nanocomposites as a function of the size of the nanomaterial.	-2.09 (1.04)	-1.41 (1.68)	0.50
6. I am familiar with the operating principles and limitations of scanning and electron probe techniques.	2.09 (0.94)	2.00 (1.11)	0.09
ABET Objectives	**Mean[1] (S.D.)**	**Mean[1] (S.D.)**	**Effect Size Difference[2]**
7. I have developed an ability to apply knowledge of mathematics, science and engineering.	2.00 (1.55)	1.73 (0.99)	0.21
8. I now have an improved understanding of professional and ethical responsibility.	1.64 (1.43)	2.09 (1.02)	-0.37
9. My ability to communicate effectively has ***not*** been improved.	-1.73 (1.10)	-1.68 (1.64)	0.04
10. The broad education I require necessary to understand the impact of engineering solutions in global and societal context has been extended.	2.18 (1.08)	1.71 (1.31)	0.40
11. I now have a better recognition of the need for, and an ability to engage in, life-long learning.	2.45 (1.03)	2.18 (0.91)	0.28
12. My knowledge of contemporary issues has ***not*** increased.	-2.09 (0.94)	-1.73 (1.60)	0.28
13. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice has increased.	2.27 (1.01)	2.18 (0.85)	0.10

Notes: [1] Ratings measured on a scale of -3 (strongly disagree) to +3 (strongly agree). [2] Effect sizes represent [(mean first field test – mean second field test) / mean s.d. of first and second field tests]. Effect sizes of 0.20 to 0.49 are small; 0.50 to 0.79 are moderate; and 0.80+ are large.

Source: ABET Course Feedback Survey, fall 2007 and fall 2008.

Nanomaterials Laboratory (CHE 59806)

Course Description

Designed to expose students to hands-on research so they are more prepared to work with faculty, the nanomaterials laboratory (CHE 59806) included five separate modules on nanotechnology that covered information from the seven modules presented in the nanomaterials lecture course (CHE 59808).

- Module 1: Chemistry – Synthesis of Nanoparticles
- Module 2: Electrical Engineering / Physics – Optical Characteristics of Nanoparticles
- Module 3: Chemical Engineering – Imaging of Nanomaterials
- Module 4: Mechanical Engineering – Mechanical Properties of Nanoparticle Reinforced Composite Materials
- Module 5: Ethical and Societal Considerations

The laboratory session associated with each module lasted approximately three weeks. Each laboratory module was led by a teaching assistant (TA) who was enrolled as a graduate student in the related program (i.e., a chemical engineering graduate student led the laboratory for this topic area). During the first week, the TAs conducted a demonstration laboratory to introduce students to the concepts, materials, procedures, and equipment. On the first day of a new module, TAs administered a short quiz to assess students' familiarity with and get them talking about the theories, content, and methods being presented in the module. As necessary, the TAs reviewed key concepts from the nanomaterials course the previous semester as a refresher for students. To prepare for the experiment, students are expected to take additional notes to supplement their laboratory manual, to ask questions, and try out the equipment.[6]

Following the demonstration, students had one to two weeks to complete the experiments in their groups with support from the TA. In some instances, when the group was able to schedule their demonstration early in the first week, they were able to begin their experiment within two days. At times, the TAs needed to review portions of the demonstration. Because the laboratory experience was designed to give students real world experience, each group was given different pre-made samples to work with to encourage them to focus on their own experiment and not simply observe the results obtained by other groups.

Finally, in the third week, student teams prepared a single laboratory report to represent the findings from their team. In both field tests, every student did the experiment, prepared a data set, and discussed it with their team member(s) prior to writing the report. This year, in some

[6] The laboratory manual and other relevant materials, including all materials from nanotechnology course, were made available to students on the Blackboard, an electronic sharing and communication tool. A review of Blackboard usage statistics indicated that students and teaching assistants accessed the Blackboard to receive and respond to announcements from the professor, to access tools provided for the laboratory experiment, and to monitor student grades on assignments. As would be expected, there was a much higher level of activity early on in the course as students became familiar with the laboratory course materials. Over time, spikes in access seemed to reflect the start of a new experiment within the course. Students varied in their use of the Blackboard with some accessing it quite a bit and others less so. Access to the Blackboard occurred throughout the day, but primarily at noon and 4 p.m. Students were most likely to use this course support on Saturdays and Sundays.

instances, it appeared that after completing and discussing their individual experiments students elected to alternate writing reports with one student writing the report for one module and the other student taking on a different module.[7]

Participant Characteristics

All of the students enrolled in the nanomaterials laboratory also completed the nanomaterials lecture course. A total of nine students, divided into three groups of two[8] and one group of three, completed the spring 2009 laboratory course.[9] Eight were majoring in Chemical Engineering and one in Mechanical Engineering.

Laboratory Reports

In both field tests, the total scores for the laboratory reports were high across the groups, averaging more than 80% of the possible 600 points per final report in the first field test and 85% or more in the second. Table 3 shows the average percent correct by module for the first and second field test.

Table 3: Percent correct on laboratory reports for nanomaterials laboratory (CHE 59806) during first and second field tests, fall 2007 and 2008.

	Spring 2008	Spring 2009
	Mean %	Mean %
Module 1: Chemistry – Synthesis of Nanoparticles	85%	85%
Module 2: Electrical Engineering / Physics – Optical Characteristics of Nanoparticles	91%	86%
Module 3: Chemical Engineering – Imaging of Nanomaterials	94%	88%
Module 4: Mechanical Engineering – Mechanical Properties of Nanoparticle Reinforced Composite Materials	81%	85%
Module 5: Ethical and Societal Considerations for Nanomaterials	89%	91%

Source: Course records, spring 2008 and spring 2009.

In looking at the scores for the six different sections within a report, students had an easier time writing up the introduction and references sections but were learning more about how to write the results, discussion, and conclusion section, as evidenced by instructor feedback and subsequent revisions. Three of the four teams opted to submit at least one revised report. All reports that were revised received higher scores, sometimes significantly higher.

[7] Observation by the faculty member overseeing the laboratory course and reviewing the reports.
[8] One group of two students worked on their laboratory activities together but prepared separate reports.
[9] Ten students completed the laboratory course in spring 2008 working in four groups of two or three students.

Course Evaluation

Students who enrolled in CHE 59806 nanomaterials laboratory completed an end-of-course evaluation. This survey gathered student opinions about the quality and utility of the course, as well as their interest/engagement.

As was true in the first field test, students in the second field test reported that students reported that the nanomaterials laboratory had the characteristics of a quality learning environment (Table 4). Students agreed that the content, pedagogy, and instructional support came together to provide an environment conducive to learning chemical engineering through laboratory research. More specifically, students felt that the expectations for learning were clear, the experiments were relevant to the field, and feedback on their performance and support from the instructor and teaching assistant were readily available. Students also agreed that "the instructional materials were complete and helpful."

With regard to the course objectives, overall, students also agreed that their knowledge of specific nanomaterials and nanotechnology concepts and principles, related skills, and understanding of ethical and contemporary issues related to nanotechnology increased as a result of their participation in the CHE 59806 nanomaterials laboratory course (see Table 5). Specifically, students generally confirmed the acquisition of the skills demonstrated in their laboratory reports:

- synthesizing nanoparticles,
- operating a spectrometer,
- analyzing and interpreting optical data,
- operating an atomic force microscope,
- analyzing and interpreting stress-strain data, and
- a familiarity with ethical issues related to nanomaterials and their applications.

In addition, students reported an increased ability to apply knowledge of mathematics, science and engineering (see Table 5).

Other ratings on the course evaluation, as well as the initial scores on individual sections of the laboratory reports, and feedback from TAs suggest that the laboratory course could be improved by enhancing students' ability to design and conduct experiments, particularly with regard to analyzing and interpreting data. In addition, students' course evaluations and the manner in which some of the teams organized their efforts to write the laboratory report indicate a need for further guidance in how to function on multidisciplinary teams and to communicate effectively. Finally, understanding of professional and ethical responsibility was another area that students felt could be enhanced.

Table 4. Mean student ratings of course quality for nanomaterials laboratory (CHE 59806) during first and second field tests, fall 2007 and 2008.

Course Quality	2007-08 Mean[1] (S.D.)	2008-09 Mean[1] (S.D.)	Effect Size Difference[2]
1. The instructor made clear the important points I had to master for this course.	2.50 (1.07)	2.43 (0.79)	0.08
2. The syllabus was followed (if there was no syllabus, circle -3)	2.75 (0.46)	2.57 (0.54)	0.36
3. The instructor and teaching assistants did ***not*** provide sufficient help in carrying out the experiments.	-2.63 (0.74)	-2.00 (1.41)	0.59
4. The experiments increased my understanding of the practice of chemical engineering.	2.50 (1.07)	2.43 (0.79)	0.08
5. The instructor was available during office hours, by e-mail, or other means of consultation.	2.88 (0.35)	2.57 (0.79)	0.54
6. All of the experiments were boring.	-1.63 (1.41)	-2.14 (0.69)	-0.49
7. All of the experiments were interesting.	1.25 (1.28)	2.00 (1.00)	-0.66
8. My ability to make oral presentations and write labs was improved.	2.00 (1.69)	2.14 (0.69)	-0.12
9. Grading of lab reports was done in a timely manner.	2.50 (0.76)	2.29 (1.11)	0.22
10. The instructor ***dis***couraged questions and class discussion.	-2.43 (1.13)	-1.71 (1.80)	0.49
11. The instructional materials were complete and helpful.	1.88 (2.10)	2.43 (0.79)	-0.38

Notes: [1] Ratings measured on a scale of -3 (strongly disagree) to +3 (strongly agree). [2] Effect sizes represent [(mean first field test – mean second field test) / mean s.d. of first and second field tests]. Effect sizes of 0.20 to 0.49 are small; 0.50 to 0.79 are moderate; and 0.80+ are large.

Source: ABET Course Feedback Survey, spring 2007 and spring 2008.

Table 5. Mean student ratings of course and ABET objectives for nanomaterials laboratory (CHE 59806) during first and second field tests, fall 2007 and 2008.

Course Objectives	2007-08 Mean[1] (S.D.)	2008-09 Mean[1] (S.D.)	Effect Size Difference[2]
1. I am able to synthesize nanoparticles using chemical synthetic routes	2.75 (0.46)	2.14 (0.90)	0.90
2. I have learned how to operate a UV/vis spectrometer to follow the synthesis of nanoparticles.	2.38 (0.74)	1.71 (1.25)	0.67
3. I can analyze and interpret absorption/emission and fluorescence data.	2.50 (0.76)	1.71 (0.95)	0.92
4. I do ***not*** know how to operate an atomic force microscope.	-2.38 (1.12)	-2.29 (0.76)	0.10
5. I am able to analyze and interpret stress-strain data.	2.63 (0.52)	2.71 (0.49)	-0.16
6. I am familiar with ethical, environmental and health-related issues associated with nanomaterials and their application.	2.50 (1.07)	2.00 (0.58)	0.61
ABET Objectives	**Mean[1] (S.D.)**	**Mean[1] (S.D.)**	**Effect Size Difference[2]**
7. I have developed an ability to apply knowledge of mathematics, science and engineering.	2.38 (1.06)	2.29 (0.49)	0.12
8. I now have the ability to design and conduct experiments, as well as to analyze and interpret data.	2.50 (1.07)	1.43 (2.15)	0.66
9. I have ***not*** acquired an ability to function on multidisciplinary teams.	-2.00 (1.78)	-1.43 (1.90)	0.31
10. I now have an improved understanding of professional and ethical responsibility.	2.38 (1.06)	1.29 (1.50)	0.85
11. My ability to communicate effectively has ***not*** been improved.	-2.13 (1.13)	-1.43 (1.81)	0.48
12. An ability to use the techniques, skills and modern engineering tools necessary for engineering practice has increased.	2.50 (1.07)	2.14 (0.69)	0.41

Notes: [1] Ratings measured on a scale of -3 (strongly disagree) to +3 (strongly agree). [2] Effect sizes represent [(mean first field test – mean second field test) / mean s.d. of first and second field tests]. Effect sizes of 0.20 to 0.49 are small; 0.50 to 0.79 are moderate; and 0.80+ are large.
Source: ABET Course Feedback Survey, spring 2007 and spring 2008

Student Engagement in the Laboratory Experience

Feedback regarding students' interest in and engagement with the laboratory experience came from the course evaluation and written feedback from the teaching assistants and students to the course instructor.

Although sometimes late to lab and varying in their level of preparedness for the most part most teaching assistants reported that students were engaged and able to successfully complete the labs within the allotted time. Student preparedness varied by student from "not preparing enough" to "well prepared" and by module; students who were prepared for other laboratory modules might not be prepared for the one in question.

Working in teams, students seemed to adjust to one another's strengths and weaknesses regarding their understanding of the scientific concepts being tested and laboratory procedures. For example, if one student was more familiar with the experimental process or had better laboratory skills, then that student might lead the experiment while the other assisted. In other groups, the students took turns.

> *"Student A was completely reliant on Student B's instructions…only did things Student B told him to do, not showing any initiative. Student A did all of the computer work and Student B did all the work on the instrument. I had wanted them to switch roles after the first experiment, but they insisted on following their existing roles…I gave in since I doubted that Student A would have been able to complete the experiment [without instructions from Student B]…so did not see what he could learn from doing the experiment himself." - teaching assistant (2009)*

> "*Student C and Student D come to lab very on time and prepared well. They cooperated very well. Student D looks like she has more lab experience. Sometimes she helped Student C and gave her some advice…Student E also came to lab very on time and prepared well. However, she was a little bit nervous and made a few mistakes. Fortunately, that didn't affect her final result." - teaching assistant (2009)*

> *"Student F paid lots of attention to the demo and carefully wrote down notes. In the experiment, he prepared well. However, obviously he has poor lab skills since he did not have chemical labs for a long time. He made a small mistake, which he may mention in his lab report." - teaching assistant (2009)*

> *"What Student G lacked in his knowledge of the material he made up for in his lab performance, showing a lot of patience in extending the sampling time of the instrument, and in using the bandpass filter, moving it ever so slightly, and waiting for the computer screen to update (it had a long sampling time)." - teaching assistant (2009)*

Student engagement sometimes led to expanded inquiry:

> *"They were attentive, though involved to the point of getting ahead of themselves. Clearly, their preparedness resulted in them not just thinking about theoretical questions*

beyond those posed in the lab manual, but also applications questions. Student H (on the second day) was inquisitive more about the theory, and Student I about how the equipment worked and how he could apply his mechanical engineering studies towards the working of the spectrometer…On day three, they went over the theory, again, asking questions going beyond what was asked for in the assignment…They asked me how the equipment that I use [for my doctoral work] operates." - teaching assistant (2009)

While students did not rate all of the laboratory modules as interesting (see Table 4), when they did, it was evident to the teaching assistants and the course instructor:

> *"[I] was extremely excited about the Module 2 [Optical Characteristics of Nanoparticles]. I learn [sic] so many things! The experiment did not came [sic] out perfect, but it made me know how the optical devices work in general." – student (2008)*
>
> *"[Module 3: Imaging of Nanoparticles] was enticing…I tend to get shivers down my spine when working with technologies that prove relationships or material properties that I read about in textbooks or learn in lecture. Nothing compares to hands-on learning." – student (2008)*
>
> *"The lab as fun, because computer got [sic] us nice images (should I say it was visual). Only drawback was that we never got the results that we expected. But on the other hand this is what research is about." – student (2008)*
>
> *"The best part of the experiment was [AFM module] where we actually prepared the nano particle sample…I really enjoyed doing that. And although operating the AFM was a little hard, I enjoyed learning how to operate it…I was amazed by the fact that we can take such nice topographic pictures of a nano size sample." – student (2009)*
>
> *"Preparing the samples was one of the parts of this experiment that I liked the most. Also the part where we got to change the tip of the AFM…it gives one the feeling of what working in a lab is like. Results are not always what we want; things that happen in a lab are unexpected and that is what makes it exciting." – student (2009)*

Student Perceptions of the Laboratory Experience

Students also provided written feedback to the course instructor on their laboratory experience including the performance of the teaching assistants assigned to each module. Overall, students felt that the demonstration conducted at the beginning of each module did have the effect of adequately preparing them to conduct their own experiments. They also commented that the experiments went well because of the detailed laboratory manual and the effectiveness of the teaching assistants. Overall, students reported that the teaching assistants provided clear and helpful information and guidance during the laboratory demonstrations of procedures and equipment, and during the actual experiments. Teaching assistants were considered knowledgeable about the theories being tested and the use of the equipment. They were also characterized as approachable and professional.

Suggestions for Improvement

Students offered some general suggestions for improvement that tended to reflect whether a teaching assistant implemented the laboratory only as outlined or whether the teaching assistant addressed needs that emerged during the sessions. For example, while some teaching assistants reported that they recognized a need to review key concepts from the nanomaterials course and during the demonstration session, others did not. In the latter instance, students were more likely to report that they wanted more information and the teaching assistant was more likely to say students needed to prepare more before coming to the laboratory.

Suggestions for improvement offered by students and teaching assistants included the following.

<u>Materials</u>:

- Update laboratory manual to include other supportive references (e.g., schematic of actual spectrometer, quantum well dispersion curves)
- Provide additional references to related research papers that would assist students in preparing laboratory reports.

<u>Format</u>:

- Conduct demonstrations and experiments on the same day to retain understanding and make the most of the time available, especially for Module 3 – Imaging of Nanoparticles.

<u>Demonstration session</u>:

- Show the laboratory set-up at the beginning to help *"visual learners"* relate the information to the actual equipment.
- Allow time for students to *"play"* with the equipment during the demonstration so there is *"less learning and tentativeness when it came time to do the actual experiments"*.

<u>Experiments</u>:

- Review basic concepts from the nanomaterials course and their importance from an application standpoint.
- Ensure that all samples are prepared properly prior to the experiment.

  "Only one of three or four polycarbonate samples worked properly. Other samples fractured outside the gauge length or at the tips, which the jaws were holding, even when the velocity was low."
- Ensure that the number of samples to be observed is suitable for the equipment.

  "The program ran pretty slow when sample number increased. Sometimes this made observation and data taking extremely irritating."
- Include more information about reference samples (e.g., particle size).

- Allow more time for students to practice certain procedures, either during the demonstration or the experiment.

  "I found picking the cantilever and placing it above the laser head [difficult], guess with practice it will be easy."

  "Experimenters should be careful on fastening the jaws. If the grip is too tight, the sample breaks at the jaw. If it is a little bit too loose, the jaw loses its grip, especially when PDMS is the subject."

With the exception of the Module 3 – Imaging experiment, all of the TAs and students said that the time allotted for the laboratory demonstrations and sessions was adequate. Laboratory sessions averaged about 2-3 hours each even with the additional time some spent reviewing basic concepts from the lecture course.

A Conversation with Students on the Nanomaterials Series

To better understand why students enrolled in the nanomaterials lecture and laboratory courses and their experiences throughout the series, the evaluator conducted a focus group with five students who completed the laboratory in 2008 and nine students who completed the laboratory in 2009.[10]

The Students

All of the students in the first focus group were majoring in chemical engineering. Four of the five students had completed both the nanomaterials course and laboratory. This group of four included two seniors, one junior, and one sophomore. The other focus group participant was a graduate student who had only taken the nanomaterials course. Nine students participated in the second focus group. Eight of the nine were majoring in chemical engineering; one was a mechanical engineering major. All of the students were seniors who had completed both the nanomaterials course and laboratory.

Why They Enrolled

The focus groups opened by asking students "Why did you want to take the nanomaterials lecture and laboratory courses?" Both years, almost all of the students said that the main reason they had signed up for the course was "*to learn more about nanoscale science and technology.*" A few students also wanted the opportunity to work with the professor: *"to learn how to write reports (knew professor gave good feedback)," "I liked the professor,"* or *"I wanted to get to know the professor to consider whether to pursue an opportunity to do research in her laboratory."*

The Nanomaterials Course and Laboratory Series

Students were then asked, "What from the nanomaterials course helped to prepare you the most for the laboratory (application) course?" Students in the group concurred that the nanomaterials

[10] The focus groups were conducted in the spring of 2008 and spring 2009, respectively.

course gave them an understanding of the core concepts they needed to know for the laboratory course. Students also agreed that the demonstration at the beginning of the laboratory experience was important in that it also served as a refresher for the theories and concepts presented in the nanomaterials course that were being examined in the experiments. Having knowledgeable teaching assistants on hand was another support when students had questions. Students also commented that the guiding questions accompanying each laboratory module were helpful because they "*forced you to get into the background research before the experiment.*"

In the second year, students were asked whether the structure of the laboratory — demonstration, experiment, report — over three weeks allowed them enough time to prepare and ask questions. Students agreed that "*if you prepared properly for the laboratory and paid attention during the demonstration,*" then, the time allotted for experiments and write-up were quite manageable. Students also commented that it was helpful when the demonstration and experiment were conducted in the same week, rather than over two weeks. Not only did this keep the concepts fresh in their minds going into the experiment, but it allowed more time for students to work through their findings and write up their reports. According to the teaching assistants, students struggled most with analysis and interpretation. Thus, having more time to focus on these tasks was helpful for students.

Students were asked, "How important was it to have interaction with the professor during the laboratory experience?" The professor taught the course, but during the second field test was only involved in the laboratory in reviewing and discussing students' reports and not in the laboratory. Students did not feel the experience was affected by the professor not being in the laboratory. "*It was fine…you can only learn by making mistakes.*"

What They Learned

When asked, "Now that you've been in the laboratory, what have you learned – knowledge and skills – that you didn't know coming into the applications course?" To this students responded that although the nanomaterials lecture course had provided an overview of equipment used in nanotechnology, students said that they needed the demonstration portion of the laboratory and the hands-on experience during the experiments to really understand how to use the equipment. Students commented that the course provided a "*good overview,*" but it was important to get into the laboratory to "*really see how to get the results and become familiar with [issues that arise during actual experiments]*."

Students were also asked whether participation in the laboratory course helped them with other courses. Students commented that they could see the connections or overlap with other courses, saying that a process or concept in the laboratory would stand out as similar to what they had learned in another course. Students also readily acknowledged the interdisciplinary connections within the nanomaterials course and laboratory experience.

When asked, "How, if at all, do you feel this laboratory experience helped prepare you for your future?" students talked about their plans. A few were considering graduate school, but most were looking to enter the job market and expected to be doing applied research. With this in mind students felt prepared to write a report on their own, although most had worked collaboratively with their team members. They agreed that the professor "*gave really good clear direction on rewrites…focus on this, more detail here.*" In addition, students said that the nanomaterials course and laboratory helped them further define their interest in working in the field with these theories and concepts.

More Advice

Finally, when asked, "What advice would you give to the faculty to improve both the nanomaterials course and the laboratory?" students had this to say:

- Offer the nanomaterials course and laboratory earlier in students' academic careers.

  Students felt that the course and laboratory were valuable in that they introduced students both to nanotechnology and to other engineering fields. Such an introduction, students felt, could help students become clearer on what would be most appropriate for them as an undergraduate major, provide a clearer focus for their graduate work, and give them enough experience to know if they would like to research.[11]

- Offer the lecture course and laboratory concurrently.

  Students felt this would help them integrate the content, demonstration, and research experiences. In this manner, they suggested that the course, which would include lecture and demonstrations, would alternate with the laboratory sessions, which would also include a brief demonstration. This, they felt, would reduce the amount of review required by students and teaching assistants during the laboratory course.

- Limit laboratory teams to two students.

  This last suggestion was a reflection of the difficulty groups had in scheduling their laboratory time when their group included three people. However, students did appreciate that the teaching assistants were flexible and could reschedule the laboratory sessions from the usual time to another to accommodate students' schedules.

- Offer demonstration and experiment in the same week.

  The demonstration was both a refresher of key content presented in the nanomaterials course and an introduction to the specific experimental and laboratory methods to be used. Reducing the time between the demonstration and the experiment helped students remember more of the fine details and procedures when actually in the laboratory. It also provided additional time for students to analyze and interpret the data, something they struggled with, and prepare the final report.

[11] The course instructor commented that ideally, the course and laboratory would be offered in students' junior year. However, the junior year schedule is already filled with other requirements. Thus, another option would be to offer the course and laboratory during the sophomore year to prepare students to work with faculty on research projects during their junior and senior years.

- Start the last module earlier.

  The last module required students to design and conduct a survey and write up the findings. Being new to survey methods, this process was much more complex and time consuming than students were aware of. And, because this module came at the end of the semester students were often caught off guard with the scope of work. Given the different nature of this module, students felt it would be helpful to offer this module earlier or at least provide a way for students to begin thinking about and discussing the steps required earlier in the laboratory experience.

Faculty Reflections

In interviews with faculty over the course of this project, several lessons learned emerged regarding the ways in which the CCNY-NUE project was structured and managed to ensure success:

- Two heads are better than one.[12]

  Faculty members recognized that the involvement of different disciplines allowed them to offer specific insights into their content area and thus strengthen the overall project (e.g., advising the project to not use gold nanoparticles for mechanical engineering experiments because it is soft and conductive).

- Opportunity for professional learning.

  Faculty members also recognized this project as an opportunity for them to learn how to work with other faculty and community partners in a collaborative manner (e.g., working together to develop a module that integrates multiple disciplines; bringing in research and development representatives from industry who could speak about academic research in an inspiring manner). Faculty members also recognized that clear expectations for involvement, strong project leadership, and building on prior relationships supported the collaboration.

- Opportunity to enhance faculty research agendas.

  Faculty members felt these collaborative relationships provided an opportunity for them to be more multi-disciplinary in their own research (e.g., considering the possible applications of including nanoscale amounts of gold or other conductive materials in polymers, which are not conductive).

- Leveraging resources.

[12] During the pilot and first field test years, the evaluator interviewed all faculty members who had been involved in the development of the modules to talk about their roles and how their involvement had influenced their own professional work. All other findings in this section were drawn from the data presented earlier in the report.

Faculty members also recognized the opportunity to "leverage" resources in a manner that supported both this project and others in which they were involved (e.g., training high school teachers how to teach the new ENGR 101 nano nugget to build a pipeline to the college).

- Capacity building over time.

  Retention of teaching assistants for the laboratory course from one year to the next meant less need for their preparation by the faculty member assigned to the course. In addition, teaching assistants who had participated previously were able to take over the task of preparing the laboratory samples.

- Opportunities for expanded inquiry.

  In their current format, the laboratory sessions can provide jumping off point for further inquiry for students that come well prepared.

Community Involvement

In addition to effectively involving faculty and teaching assistants in the development of the nanotechnology modules, the project also provided students the opportunity to hear from members of the scientific community who work in industry. The nanomaterials course included talks by visitors who came to share their perspectives on nanotechnology and its applications in the field. These visitors were impressed by the project and faculty and felt that their involvement benefited their organizations as well. This is what they had to say:

> *"I would definitely consider doing this again. I was quite impressed by the work people are doing, and I think you guys have the makings of a promising, up and coming department...From a Cabot perspective I can say that these types of visits are generally good…we do pay attention to academic research and like to maintain ties with the community at large. It's a convenient way to keep tables on what academia is doing in a very informal and personal way…Several people at Cabot were quite intrigued by my comments about my visit [and will be following up with CCNY-NUE faculty]. – Research Engineer, Cabot, Inc.*

> *"…thanks for the opportunity. I heard about some good research ([CCNY-NUE faculty member] sent me some publications and I especially enjoyed hearing about your Janus particles)…it was fun to meet the students and to see the University buildings." -- Research Staff Member , IBM*

Another benefit of partnering with industry partners is that under normal circumstances they invite students from the CCNY-NUE program to submit resumes directly to them. However, at the present time both organizations have hiring freezes as a result of the recent economic downturn.

Summary

In the first field test, the evaluation data provides evidence that the CCNY-NUE team was successful in developing and implementing nanotechnology coursework, laboratory experiences, and mini-“nano nuggets” modules that engage students and promote learning of knowledge and skills relevant to engineering and to nanotechnology. The second field test validated previous findings in demonstrating for a second time the success of this project:

> Students are learning key nanotechnology theories and concepts and are able to successfully apply that learning a laboratory setting.

In addition, the evaluation also revealed opportunities to enhance the program to further improve its effectiveness. Specifically, students’ would benefit from further developing their scientific skills:

- Students need more guidance on how to conduct experiments, including skills relevant to laboratory work and analyzing and interpreting data.

  Students and teaching assistants agreed that the experiments themselves were of the appropriate level of sophistication (i.e., not too hard), but that “*the issue [challenge] is data interpretation.” – teaching assistant (2009)*

  In addition, students struggled with some of the less tangible skills necessary for scientific inquiry:

  “I am not sure how to prepare the students, mentally, for the challenge of conducting experiments that will test their patience (the bandpass filter experiment in particular…). Towards the end of the experiment sessions, I have seen the groups’ expectations for the kind of results they will get from my module fading…I keep telling them that in the real world one has to try, and try again, to verify, and that engineering is a tedious process, but that does not seem to keep them satisfied. While I cannot blame them, for I was like them too, I do find myself a bit disappointed when that does not quiet down someone who has finished senior design. I suppose their discomfort from despair, and impatience, is just part of their growing pains.” – teaching assistant (2009)

- Students need more guidance in communicating what they know both verbally and in writing.

  “The students seem like they are concerned about giving a textbook response to the review questions, rather than conveying simply what they understand. I often feel that the students know the answer, but they just cannot find the words. At other times, I feel that they are reciting words that they do not understand. I cannot blame them for this, because I personally do not think that it is possible to be comfortable with the physics over the course of a year; rather, such familiarity results from repeated exposures, from different perspectives, over many years.” – teaching assistant (2009)

“*I needed to spend a lot of time helping students understand ‘real research’…that the report is what you understand [from the experiment], not just what you put in it. You have to assume that the reader has no knowledge and convey what you are seeing in the data.” – teaching assistant (2009)*