International Conference on Engineering Education and Research "Progress Through Partnership"

Nanotechnology Exposure in a First-Year Engineering Program

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KEYWORDS: *nanotechnology, first-year, freshman*

ABSTRACT: *The estimated demand for nanotechnology workers presents a special challenge and opportunity to restructure teaching and curricula at all levels to include nanotechnology concepts and nurture the scientific and technical workforce of the 21st century. A new generation of skilled scientific workers must be educated and trained with a multidisciplinary perspective to participate in the rapid advances in nanotechnology. The interdisciplinary nature of nanoscale science and engineering provides new opportunities for interdisciplinary course and curriculum development. Of particular interest are the advances in nanotechnology research that provide new opportunities in undergraduate education including course and curriculum development. To date, graduate and senior level courses have been the primary focus for nano-education development and little attention has been given to lower division engineering students.*

In Fall 2003, we began implementing a series of three collaborative taught course innovations to engaging first-year engineering students in learning and discovery experiences in nanotechnology. The broad goal of this work is to educate a new generation of engineers about this emerging technology. Assessment strategies are being employed to study the impact of exposure to nanotechnology on their selection of major, their interest, motivation, and persistence in solving nanotechnology based problems, and their level of interest in pursuing future nano-scale related coursework or undergraduate research activities. This paper will overview the course innovations and the assessment strategies that are in progress.

1 INTRODUCTION

It is estimated that about 2 million nanotechnology workers will be needed worldwide in 10-15 years, with 0.8-0.9 million in the U.S. alone (Roco, 2001). This presents a special challenge and opportunity to restructure teaching and curricula at all levels to include nanotechnology concepts and nurture the scientific and technical workforce of the 21st century. Educating and training a new generation of skilled scientific workers with the multidisciplinary perspective necessary for rapid advances in nanotechnology is one of the key transforming strategies of the U.S. National Nanotechnology Initiative (NNI).

The interdisciplinary nature of nanoscale science and engineering – its blending of chemistry, physics, biology, mathematics, computer science, materials science, geology, engineering, etc. – also provides new opportunities for interdisciplinary course and curriculum development, as well as faculty collaboration, both in teaching and in research, that cross traditional disciplinary departmental boundaries (NSF,2002a). Of particular interest are the advances in nanotechnology research that provide new opportunities in undergraduate education including course and curriculum development and new research opportunities. Nanoscale science and engineering provide a multitude of new interdisciplinary teaching opportunities for engaging the interest of students and for broadening their vision of science, engineering, and technology. Nanoscale science and engineering thus permit new strategies for enhancing science literacy, preparing the workforce for emerging technologies, and attracting a diverse group of talented students to the workforce of tomorrow. To date, graduate and senior level courses have been the primary focus for nano-education development and little attention has been given to lower division engineering students.

A wide variety of nanotechnology educational programs are in various stages of development and implementation across the United States and in other nations, spanning K-12, associate and baccalaureate degree levels and, graduate programs, and informal education programs (Roco, 2002). Nanotechnology education efforts are underway as part of the public outreach components of major National Science Foundation (NSF) nanotechnology research centers. The need for expanded nanotechnology undergraduate education is increasingly recognized (NSF, 2002b). This is especially true at the freshman level which, until recently, had been relatively ignored. In fiscal year 2003, NSF support a number of course innovations focused on providing freshman engineers with exposure to nanotechnology, including innovations being implemented at University of Notre Dame (NSF 0304089), California Institute of Technology (NSF 0304713), and Ohio State University (NSF 0304469).

There are currently no four-year degree undergraduate programs dedicated to nanotechnology in the United States. However, there has been success in designing and implementing courses and research projects for undergraduates at the junior and senior levels in biology, chemistry, engineering and materials science (NSF, 2002b). Currently, only a small number of universities in the U.S., Europe, Australia, and Japan offer selective graduate programs in nanoscience and nanotechnology in collaboration with research centers. In addition, only a handful of universities, including Virginia Commonwealth University, Penn State University, and Flinders University in Australia (Uddin and Chowdbury, 2001) offer undergraduate engineering courses as part of an associate degree or a certificate program in nanoscience or nanotechnology. To prepare our students to solve the technological challenges of the new millennium, nanotechnology education should be incorporated into the mainstream undergraduate engineering curriculum.

Nanoscale concepts should penetrate the education system in the next decade in a similar manner to how the microscopic concepts and technology made inroads in the last 50 years (Roco, 2003). Attention now to the development of interdisciplinary education programs that engage the interest of students of all ages especially at the undergraduate level is critical to insure leadership in the area of nanotechnology and to foster an accelerated transfer of knowledge from research activities to education. Focusing on the first and second year of undergraduate education (and two-year college programs) will help to encourage and prepare students to pursue further education in the area of nanotechnology (NSF, 2002b).

In academic year 2003-04, we implemented three collaboratively taught course innovations to engaging first-year engineering students in learning and discovery experiences in nanotechnology. These innovations included:

- A nano-scale engineering themed seminar series for first-year engineering students based on an existing seminar series framework that introduces students to various engineering disciplines,
- A nanotechnology-based mathematical modeling activity for use in an existing first-year engineering problem solving and computer tools course, and
- A new one-credit first-year research course that consists of a set of laboratory / discovery experiences for a small group of first-year engineering students.

These innovations were implemented through the Purdue University Freshman Engineering Program (FrE), which serves as the gateway to the Purdue Schools of Engineering. FrE is somewhat unique in the U.S. as Purdue engineering students find it "legal and acceptable" to be undecided in their major of choice and are given two semesters to make a decision. The FrE curriculum prepares students for major selection and transfer to the engineering disciplinary schools as sophomore level students. All of the students completing the FrE core curriculum are admissible as sophomores to the professional degree programs at Purdue.

The broad goal of this work is to educate a new generation of engineers about this emerging technology. This paper will overview the course innovations and the assessment strategies that are in progress. Preliminary results are also presented.

2 NANO-THEMED SEMINAR

In their first semester at Purdue, first-year engineering students must take ENGR 100– Freshman Engineering Lectures or 100H – Honors Freshman Engineering Lectures. The traditional paradigm for this one-credit class has a faculty member from each engineering school at Purdue deliver a fifty-minute seminar regarding their specific program and opportunities in their field. The objectives of the course are to enable students to: (1) chose a field of engineering to study and (2) understand the academic and career opportunities within the different fields of engineering.

The traditional course structure of one division of ENGR 100, called ENGR 100S (N = 329), and the entire ENGR 100H course (N = 187) was modified to include a nano-theme throughout the semester. Leading faculty from within the Schools of Engineering made presentations on the current state of nanoscale technologies and discussed the broader impact of the engineering disciplines. In ENGR 100S, lecturers spent half of the 50-minute period informing students about their program and the other half discussing nanotechnology as it relates to their discipline of engineering. In ENGR 100H, two different departments made presentations in the 50-minute period. Each lecturers spoke only on the relationship of nanotechnology to their disciplines. Table 1 summarizes the departments and presenters for the ENGR 100S and ENGR 100H classes and notes the emphasis of their nano-themed presentation.

Table 1. Engineering disciplines presenting a nano-themed seminar in ENGR 100S or 100H.

Engineering Discipline	**ENGR 100S Presenter**	**ENGR 100H Presenter**
Aeronautical & Astronautical	T. Farris	P.K. Imbrie
Agricultural and Biological	M. Ladisch	V. Bralts
Biomedical	A. Ivanisevic	A. Ivanisevic
Chemical	M. Harris	M. Harris
Civil	---	K. Banks
Electrical	D. Jones	M. Lundstrom
Industrial	C. Chandrasekar	C. Chandrasekar
Materials Science	A. King	A. King
Mechanical	S. Wereley	S. Wereley
Nuclear	R. Taleyarkhan	T. Jevremovic

3 NANO-BASED MODEL ELICITING ACTIVITY

All first-year engineering students are required to complete either ENGR 106 – Engineering Problem Solving and Computer Tools or the honors versions of the course, ENGR 116. These courses are designed to give students an appreciation for what the pursuit of an engineering degree entails. The course learning objectives are such that students successfully completing the course are able to:

- Develop a logical problem solving process which includes sequential structures, conditional structures, and repetition structures for fundamental engineering problems,
- Translate a written problem statement into a mathematical model,

- Solve fundamental engineering problems using computer tools,
- Perform basic file management tasks using an appropriate computer tool,
- Work effectively and ethically as a member of a technical team, and
- Develop a work ethic appropriate for the engineering profession.

The syllabus is a coordinated mix of introduction to engineering fundamentals, including graphical representation, statistics, and economics, and introduction to computer tools used to solve engineering problems, specifically MATLAB, Excel, and UNIX. ENGR 106 has two 50-minute lectures and one 2-hour computer laboratory period per week; ENGR 116 has three 50-minute lectures and one 2-hour lab period per week. The lectures focus on fundamental engineering concepts and problem solving. Lab tasks walk student teams through the use of new computer tool syntax/procedures and simple fundamental engineering problems. Students then apply the theory learned in lecture and the syntax/procedures learned in lab to the solution of problems with engineering context.

A nano-based model-eliciting activity (MEA) and follow-up homework and project were developed for and implemented in the Fall 2003 offering of ENGR 106. No similar nano-based activity was developed for ENGR 116 (N = 183). A model-eliciting activity is a real-world, client-driven open-ended problem designed from a models and modeling perspective (Lesh, et al., 2000). The use of MEAs in ENGR 106 and associated opportunities and challenges are discussed elsewhere (Diefes-Dux, Follman, et al., 2004, Diefes-Dux, Moore, et al., 2004, Moore & Diefes-Dux, 2004).

The MEA, called *Nano Roughness*, was developed to provide freshman engineering students (N = 1468) with a hands-on experience with relevant scientific and mathematical concepts used in nanoscale technologies and research. The MEA was completed in the laboratory setting and required students to develop a procedure to measure roughness given atomic force microscope (AFM) images of three different samples of gold (Figure 1). This problem was set in a realistic context in which a company specializing in biomedical applications of nanotechnology wishes to start producing synthetic diamond coatings for joint replacements. The company intends to extend its experience with gold coatings for artery stents to this new application. Student teams of four are required to establish a procedure for measuring the roughness of gold samples that could be applied to diamond samples. The students apply their procedure to three different samples of gold and develop a list of additional information they need to improve their procedure.

In a follow up homework assignment, students learn about the average maximum profile (AMP) method. This is one of many techniques used to quantify roughness using AFM images. A line is drawn across the image and a height profile is generated (Figure 2). The AMP is the average of the difference between the heights of the ten highest peaks and the ten deepest valleys. Student teams are asked to compare their method to the AMP method by: (1) discussing the similarities and differences between the methods, (2) using both methods to quantify roughness for three images, and (3) indicating the ways the AMP method lends itself to the development of a software tool.

Finally, in a six-week project, student teams used MATLAB, to develop a software tool to generate an AFM image from a data file containing a listing of height measurements made at (x,y) locations across a sample surface and implement the AMP and other roughness measures. This project allowed students to put into practice their knowledge of flow-charting, user-defined functions, repetition and flow control structures, 2-dimensional array manipulations, and reliability considerations (statistics).

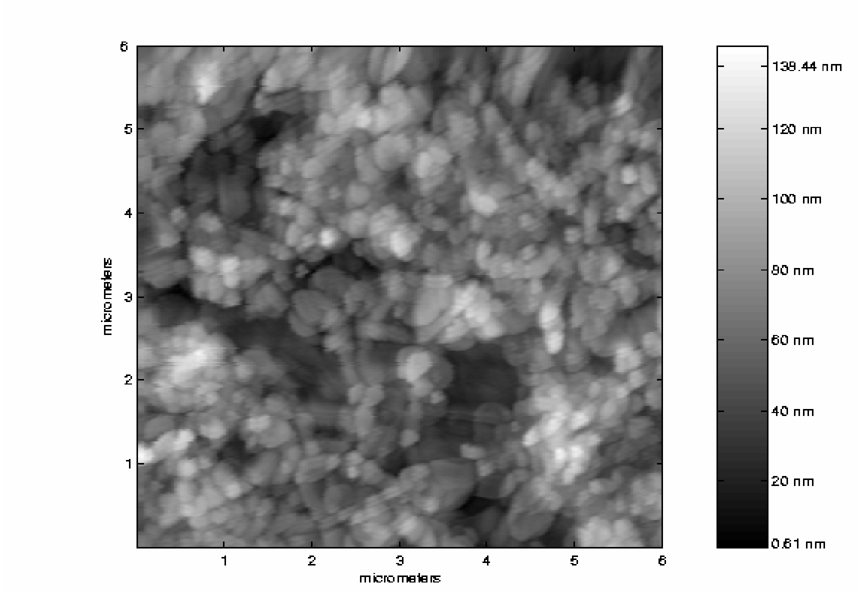

Figure 1 – AFM image Sample A
(AFM data courtesy of Purdue Nanoscale Physics Lab)..

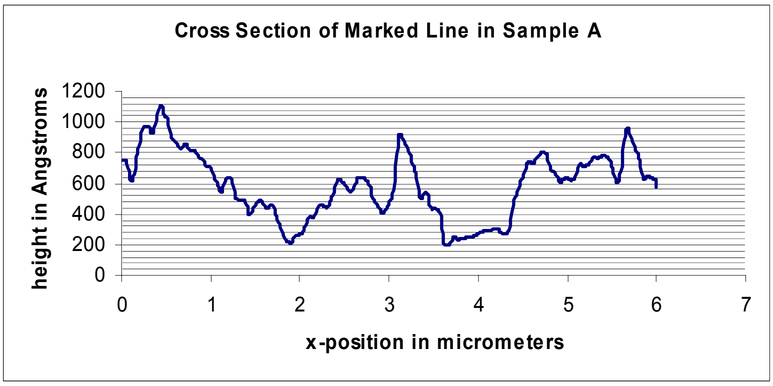

Figure 2 – Profile along horizontal line drawn at
2.3 micrometers across Sample A.

4 NANO DISCOVERY EXPERIENCE

A new research and discovery experience course was developed and implemented in Spring 2004. It focused on introducing students to basic research methods and nanotechnology-based manufacturing and characterization processes. The course was offered to students who had been enrolled in either ENGR 100S or ENGR 100H; total course enrollment was 22. The course learning objectives were such that successful completion of this course will enabled students to:

- Develop a research plan and write a research paper
- Perform a literature review to support the research plan
- Explain the difference between top-down and bottom-up use of nanotechnology
- Describe soft lithography and explain the steps involved in producing masks
- Describe uses of atomic force microscopy and explain the steps in imaging/and or modifying patterns produced using soft lithography
- Develop and practice your technical presentation and writing skills

In the first six lecture periods, students were introduced to basic research methods and fundamental concepts in nanotechnology. Student teams then had laboratory experiences with soft lithography, the atomic force microscope (AFM), and other scanning probe methods. The soft lithography experience provided hands-on experience on top-down nanofabrication techniques. The AFM experience exposed students to metrology and fabrication techniques of choice in nanotechnology. This course concluded with an oral presentation on students findings in their discovery experience.

In the soft lithography lab, students used a standard desktop graphics package, such as Adobe Photoshop, to create a design. Students then calculated the optical reduction factors necessary to achieve final mask dimensions for subsequent photography. Students printed their final designs on transparencies and placed them on a light box. A standard 35mm camera captured the image on specialized 35 mm film.

Following film development, students performed spin-coat photoresist (SU-8) to a specified thickness. They then patterned the photoresist using a projection mask aligner and develop the patterned resist to create a mold master. A molded MEMs device was created using polydimethylsiloxane (PDMS). Microcontact printing used the relief structures on the surface of a PDMS part as a stamp to transfer a pattern of self-assembled monolayers (SAMs) to the substrate surface by contact. SAMs were created by immersion of the substrate in a solution containing a ligand $Y(CH_2)_nX$, where X is the head group and Y is the anchoring group. The head group determines the surface property of the monolayer. In microcontact printing, the stamp is wetted with the above solution and pressed on the substrate surface.

Metrology is a key component of manufacturing at the micro/nanoscale. Accurate, high resolution measurements of microfabricated devices are essential for quality control of micro/nanofabrication processes. AFM and other scanning probe methods are increasingly becoming the metrology technique of choice. Students were exposed to the basic modes of operation of AFM (tapping mode, contact mode). AFM was used to image and modify patterns produced in the soft lithography laboratory experience.

At the conclusion of the course, students submitted a final report (both orally and in written form) based on their lab results. The final report will covered analysis of the AFM results, including surface profiles and characterization of nano/microscale surface roughness of the chosen samples.

5 ASSESSMENT STRATEGIES

Assessment strategies are being employed to study the impact of exposure to nanotechnology on first-year students' awareness of nanotechnology; selection of major; their interest, motivation, and persistence in solving nanotechnology based problems; and their level of interest in pursuing future nano-scale related coursework or undergraduate research activities. Table 2 summarizes the course combinations in which students were enrolled with and without exposure to nanotechnology in the Fall 2003 semester.

Table 2. Freshman engineering course combinations for Fall 2003 with and without nanotechnology course innovations.

	Problem solving course *with* nano-based MEA	Problem solving course *without* nano-based MEA
Seminar series *with* nano-theme	ENGR 100S & ENGR 106 ENGR 100H & ENGR 106	ENGR 100H & ENGR 116
Seminar series *without* nano-theme	ENGR 100 & ENGR 106	ENGR 100 & ENGR 116

A Nano-Awareness Survey was developed to assess students change in awareness of nanotechnology. This survey was conducted in a pre-post fashion at the beginning and end of the Fall 2003 semester. A series of questions asked students about their knowledge of nanotechnology before coming to college and following their first semester in the freshman engineering program. On the post-test, students were asked to rate the level to which the seminar and problem solving course influenced their awareness of nanotechnology. In addition, the students were asked a series of open-ended questions to provide qualitative data about their understanding of nanotechnology and its applications. For instance, students were asked to list some of the properties of matter that nanotechnology is currently being used manipulated. Students were also asked, "What are some of the potential societal impacts of nanotechnology?" Quantitative and qualitative analysis of responses to these questions will demonstrate whether the seminar and problem-solving course innovations impact students' awareness of nanotechnology and the nature of change in their awareness.

A Majors Survey was used to track students' first and second choice of engineering major and their confidence in their selection. Students also indicate what influences their major selection; responses are selected from a comprehensive list which included courses, family, and self-exploration. Students completed this survey four times during the fall semester. This data will be used to assess the impact of student's exposure to nanotechnology on their selection of major.

A number of assessment strategies, developed for an NSF Gender Equity project, were used to evaluate the use of the nano-based MEA in ENGR 106. The Lab Reflection is a quantitative and qualitative tool used to assess students' interest, motivation, and persistence in completing lab tasks. Qualitative analysis of students work provides insight into students' level and quality of participation, their thought processes during model development, and their understanding of nanoscale and nanotechnology.

The number of applicants for the discovery experience is an indicator of the resulting interest in nanotechnology from first to second semester. In the research and discovery experience, students' written work will be used to assess their understanding of soft lithography and scanning probe techniques. Students' level of interest in pursuing future nanoscale related coursework or undergraduate research activities was assessed at the end of the course.

Course evaluations were used across all three types of courses in which nano-based course innovations were implemented. Students evaluate the course against the course learning objectives stated in the course syllabi. Students also provide qualitative feedback on what helped and hindered their achievement of course learning objectives.

6 PRELIMINARY RESULTS

Data analysis has only just begun on data collected during the Fall 2003 semester. Presented here is a selection of preliminary findings from the Nano-Awareness Survey. Of the students completing the pre-test survey and enrolled in any seminar (N = 791), 91% reported having heard the term "nanotechnology". Table 3 provides some insight into students' awareness of nanotechnology prior to starting college. Students "agreed" or "strongly agreed" that they had frequently heard the term "nanotechnology" and could envision what the term refers to at a rate of 35% and 51%, respectively. However, they were less likely to agree that they actively sought out information about nanotechnology or nanotechnology undergraduate research opportunities.

Table 4 shows that 47% of students "agree" or "strongly agree" that they wish their high school teachers provided them with a better awareness of nanotechnology. This might be the reason for less agreement about pursuing work with a company that works with nanotechnology (20%) or wishing there was a specific nanotechnology degree program (24%). While 57% of the students "disagree" or "strongly disagree" there is too much hype about nanotechnology, few students agree that they know which engineering disciplines are involved in nanotechnology or companies that create nanotechnology devices.

Table 3. Students' classification of their awareness of nanotechnology prior to starting college (N = 791).

Before coming to college, …	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I frequently heard the term "nanotechnology" used	17%	26%	21%	24%	11%
When I heard someone use the term "nanotechnology," I could envision what he/she was referring to	13%	18%	17%	36%	15%
I actively sought out information about nanotechnology by reading newspapers, magazines, books, and/or internet articles.	35%	36%	15%	9%	4%
I attempted to learn about educational programs that are available as an undergraduate student in the area of nanotechnology.	39%	41%	14%	5%	1%
I attempted to learn about undergraduate research opportunities that are available in the area of nanotechnology.	40%	42%	12%	5%	2%

Table 4. Students' classification of their awareness of nanotechnology prior to starting college (N = 791).

Item	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I wish my high school teachers would have provided me with a better awareness of nanotechnology.	8%	16%	29%	36%	11%
After graduating from college, I would like to work for a company that is developing nanotechnology applications.	11%	17%	53%	15%	5%
I wish there was a specific nanotechnology engineering program.	10%	14%	52%	18%	6%
I know which engineering disciplines offer opportunities to be involved with nanotechnology projects.	16%	36%	24%	20%	4%
I know the names of at least six companies that are currently working to create nanotechnology devices.	41%	39%	12%	6%	2%
I think there is too much hype about the future impact of nanotechnology.	25%	32%	36%	4%	3%

Table 5 show the students indicated level of influence of the nano-themed seminar series and nano problem had on their awareness of nanotechnology. As for the seminar series, 62% of the students responding to the Nano-Awareness Survey and enrolled in a nano-themed seminar indicated an influence level of "distinctly" or "significantly", as opposed to 18% of students in a seminar series without a nano-theme.

In Table 5, a distinction is made between the influence of the lecture, lab, and homework/project components of the engineering problem solving courses on awareness of nanotechnology. It is not surprising that students in both ENGR 106 (with nano-based MEA) and ENGR 116 (without nano-based MEA) did not respond differently about the influence lecture had on their awareness of nanotechnology as there was no lecture time devoted to nano-concepts in either course. While students in both courses, did not rate the influence of lab highly, 11% of students in ENGR 106 responded with "distinctly" or "significantly" influenced. While 0% of students in ENGR 116 responded similarly. Finally, 24% of students in ENGR 106 responded that the homeworks or projects "distinctly" or "significantly" influenced their awareness of nanotechnology; 0% of students in ENGR 116 responded similarly.

It is recognized that the quantitative data does not reflect the nature of any increase in awareness of nanotechnology. Analysis of the qualitative data should provide this information.

7 CONCLUSIONS

Nanotechnology will enter our lives in a significant manner in 10-15 years. Yet, the availability of sufficient scientists and industrial experts is in question unless education practices change (Roco, April 2002). One may consider changes in the way we structure the delivery of information on nanotechnology to improve learning and dissemination of the results of research and development. A first step in growing the technological workforce is to inform and engage first-year students who are undecided about their future studies in engineering about the opportunities afforded by the emerging field of nanotechnology. The preliminary results of this study indicate that students are hearing the term "nanotechnology" before entering the university but their awareness level is in question. Through first-year course innovations, such as those presented, there is the potential to raise students' awareness and direct them toward future studies and experiences that will enable them to work in and drive the nanotechnology field.

ACKNOWLEDGEMENTS

The authors acknowledge the support of the National Science Foundation (NUE-0304579; Award Title: New Learning and Discovery Experiences in Nanoscale Engineering Undergraduate Education)

Table 5. Level of influence of course innovation on students' reported awareness of nanotechnology

Course Innovation	Students (N)	Had No Influence	Slightly Influenced	Noticeably Influenced	Distinctly Influenced	Significantly Influenced
Seminar series *with* nano-theme[a]	288	2%	13%	23%	23%	39%
Seminar series *without* nano-theme[b]	503	21%	37%	24%	12%	6%
Lecture: Problem solving course *with* nano-based MEA[c]	215	40%	33%	21%	4%	1%
Lecture: Problem solving course *without* nano-based MEA[d]	73	41%	33%	22%	4%	0%
Lab: Problem solving course *with* nano-based MEA[c]	215	25%	35%	28%	8%	3%
Lab: Problem solving course *without* nano-based MEA[d]	73	77%	19%	4%	0%	0%
Homeworks/Projects: Problem solving course *with* nano-based MEA[c]	215	17%	29%	30%	19%	5%
Homeworks/Projects: Problem solving course *without* nano-based MEA[d]	73	81%	14%	5%	0%	0%

[a] Students in ENGR 100S and ENGR 100H
[b] Students in ENGR 100 without a nano-theme
[c] Students in ENGR 106 and either ENGR 100S or 100H
[d] Students in ENGR 116 and either ENGR 100S or 100H

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