Nanotechnology for Engineering Education: a Frontier in Taiwan

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KEYWORDS: *MEMS, NEMS, nano-scale science, nano-technology, certified curriculum*

ABSTRACT: *The nanotechnology curriculum at National Taiwan University (NTU), started in 2002 is the first minor-level equivalence program in the subject in Taiwan. The program was initiated by the Dean of College of Engineering in 2001 and developed under supervise of an advisory committee. The program is highly multi-disciplinary oriented with faculty contribution from nine academic departments across three colleges. Emphasis in class lectures and hands-on experiments, the program has attracted strongly motivated students with a total number of exceeding 500 students came from twenty-six academic departments across six colleges. Without the strong academic capability and administrative support at NTU, this program will not be such successful. Internet based course structure and assessment, web resources, and partnership strategy are described.*

1 INTRODUCTION

As pointed out by Roco, et al. that preparation of the nanotechnology workforce for the next decade is a major challenge for the progress of this new technology. It was estimated that about 2 million workers will be needed worldwide in 10-15 years from 2002.

Engineers facing the challenge of multi-disciplinary nature of the nanotechnology, they need to build up fundamental understanding in electronics, ceramics, polymers, electronics, optics, mechanics, chemistry and biology, etc. In response to the high level workforce needs in Taiwan, particularly in the nano-electronics, nano-materials, nano-electro-mechanical devices, information technology, and bio-technology areas, the nanotechnology curriculum was first initiated by the Dean of the College of Engineering in 2001. And later in collaboration with the College of Electrical Engineering and Computer Science, the program was officially established in February 2002 in the NTU. It was considered the ever first of such curriculum in Taiwan.

At the early stage of the program, an Advisory Committee was organized by the Dean of the College of Engineering with advisory members from different departments across two colleges. The committee meeting was held at least two times a year to revise contents of the curriculum and review administration strategy. The committee members are critical in coordinating the new courses in each department and in prompting the success of the program. Without the strong academic background and administrative support at NTU, such program will not be established. In the following, course detail contents, experiment hands-on training, statistics data and operation strategy will be described.

2 THE CURICULUM PROGRAM

In developing this new, yet at its infancy and is extremely broad range of the nanotechnology, effectively ruling out a main strategy to comply and integrate expertise of existing NTU strength is the main target. During the development of the curriculum, much effort was at focus of balance of the

contents of science and engineering, lecture and hands-on experimental training. The design of the curriculum incorporates academic requirements to cover fundamental physics, chemistry, materials, mechanics, electronics, photonics, control, and measurement. Therefore, student will complete courses offered in College of Engineering, College of Science and College of Electrical Engineering and Computer Science. It is the goal of training students with knowledge from macroscopic to molecular and atomic levels, and yet with hands-on skills.

Table 1 Core course structure for the Nanotechnology Curriculum at National Taiwan University

Course title (3 semester credit-hours each)	In charge department	College
Introduction to Nanotechnology	Department of Mechanical Engineering	College of Engineering
Nano-scale materials	Department of Material Science	College of Engineering
Nano-scale electronics	Department of Electrical Engineering	College of Electrical Engineering and Computer Science
Nano-scale photonics	Institute of Opto-electronics	College of Electrical Engineering and Computer Science
Quantum mechanics	Institute of Applied Mechanics	College of Engineering
Introduction to Nano-scale Science	Department of. Physics, Department of Chemistry,	College of Science
Nano-scale fabrication	Department of Mechanical Engineering	College of Engineering
Nano-scale measurement Technique	Department of Mechanical Engineering	College of Engineering
Nanotechnology Experiment (I), (II)	Department of Chemistry, Department of Physics, Center for Nano-Science and Technology, NEMS Research Center, Center for Condensed Matter Sciences and several departments	College of Science, College of Engineering, and College of Electrical Eng. And Computer Science

The completion of the curriculum requires 20 credit-hour courses, which is equivalent to the minor degree at the university. The 20 credit-hour courses require completion of 3 of core courses in addition to 4 general courses. The core courses in the curriculum listed in Table 1 has shown the multi-disciplinary nature of the program. The general courses which included related fundamental courses in science and engineering are too many to be listed here.

Table 2. Course schedule for "Introduction of Nanotechnology" (3 semester credit-ours)

Week	Topics
1	Introduction
2	Fundamentals of nanotechnology
3	Nano-scale materials
4	Nano-scale thermo and fluidics
5	Traceability of nano-scale metrology
6	Nano-scale measurement technique
7	Scanning probe microscopy control
8	1D nano-scale materials, carbon tubes and nano-scale wires
9	Student project presentation (10 min each group)
10	Nano-scale fabrication technique
11	Nanotechnology in Bio applications
12	Nanometer positioning and nano-scale manipulation
13	Nano-scale data storage applications
14	Nano-scale devices and applications
15	Advanced basic nano-scale science
16	Student oral presentation
17	Student oral presentation
18	Final exam (close book test)

Taking the course "Introduction of Nanotechnology" as an example. With its outline listed in Table 2, it shows variety inclusions of the contents which is more engineering oriented. It covers the nano-scale materials, synthesis, fabrication, thermal-fluid-solid mechanics, metrology, AFM, STM, biotechnology, energy storage, information storage, and devices applications. Lectures were team-taught by faculty members from NTU and other universities, as well as from industries. Experiments and field trip to visit MEMS/nanotechnology laboratory are included in the course. Students are also required to form small team to carry out research topics. Among 25 topics with relevant key papers will be posted in web site for selection. Since students coming from variety of background, student presentation will mutually benefit each other in a great deal. For instance, students of Chemical Engineering major talk about the synthesis method for cathode film of fuel cells. Students of Mechanical Engineering major will talk about the AFM data storage techniques. Students of Environmental Engineering talked the preventive issue of carbon nano-tubes in human body. The final grade is based on final close book test, experimental assignment, and the final oral presentation.

For the "Introduction of Nano-scale Science" course, which was designed by Prof. Y. F. Chen, Department of Physics, College of Science. In complimentary to the "Introduction of Nanotechnology" course, it focuses on the basic theoretical science contents as shown in Table 3. The synthesis, deposition method, and modern instrumentation for nano-scale characterization techniques were all covered. At the end of the course, 9 hours lectures were given on the engineering applications in NEMS device, polymer and semi-conductor devices. The dedicated 3 semester credit-hours course on nano-materials is offered by faculty in Institute of Material Science. It covers electronic, chemical, mechanical material properties, top-down and bottom-up synthesis process, carbon based, Silicon based and biological materials, and safety issues. In terms of the nano-scale computation and simulation, several topics, such as MEMSCAD, ANSYS (finite element analysis), and simulation software for circuit design, photonics, nano-scale energy state and molecular dynamics are available in PC-cluster environment. The experimental courses are described in the next section.

Table 3 Course outline for "Introduction of Nano-scale Science" (3 semester credit-hours)

Chapter	Contents	In charge department
Quantum mechanics	Quantum theory Atomic and molecular structure Quantum physics and applications	Dept. of Physics
Solid state science	Solid state crystal structures Bad energy, Electric, optical, magnetic and mechanics of solid state structures	Dept. of Physics
Chemical properties of nano-materials	Physical, chemical vapour deposition growth techniques Metallic, semi-conductor and insulator Nano-materials Molecular self assembly Molecular devices applications in catalyst, energy storage and bio-inspection	Dept. of Chemistry
Physical properties of nano-materials	Nano-structure and morphology Element composition and bond structures, Porous analysis Spectrum and single molecular structure analysis	Centre for Condensed Matter Sciences
Nano-devices and applications	Nano-manipulation and NEMS devices Nano-ploymer materials Semi-conductor devices	Dept. of Mechanical Eng.; NEMS Research Center, Dept. of Chemical Eng. and Dept. of Electrical Eng.

3 HANDS-ON EXPERIMENT TRAINING

The hands-on experimental courses are specifically emphasized. Special funding was allocated for facility and equipments. It includes the micro/nano-scale clean room fabrication process, and the Nanotechnology Experiments (I) and (II) courses. The fabrication process courses are offered by the Nano-Electro-Mechanical–System Research Center (NEMS Center) at the National Taiwan University. The course covers the full line of the MEMS technology. It includes computer aided design (MEMCAD), thin film deposition, photo-lithography, etching, packaging and testing. Statistics data of both number of training courses and number of users for year 2000 to year 2003 is listed in Table 4

The data in the table shows that the hands-on training courses are offered to a small group, 2 to 4 students in one lecture of 3 to 5 hours. NA (not available) in the table is due to different equipment purchase year and training courses were then offered at different starting dates. In average, one course per each week has been offered. After the training, students will practice the operation and then register for certificate examination at his/her own interest. Students holding a clean room certificate have been benefited as a strong qualification on his/her job hunting. Over years, those graduate students with strong MEMS fabrication skills gradually become the major work force in Taiwan MEMS fabrication industries. The essence and uniqueness of the teaching method has been proved the most effective way.

The above mentioned NEMS Research Center was established in 1998 with grant support from National Science Council and NTU. It is essentially a regional facility centre for MEMS/NEMS fabrication. Over the past 5 years, partnership with over 20 universities, colleges, and industry has been established to enhance the workforce preparation in Taiwan.

Table 4 MEMS technology hands-on training courses and yearly statistics (NA: not available)

MEMS Hands-on training courses	**Y2000**		**Y2001**		**Y2002**		**Y2003**	
	No of courses	No of users	No of courses	No of users	No of courses	No of users	No of courses	No of Users
Safety training	12	226	12	335	13	294	15	346
Surface profiler	26	85	26	90	43	93	29	74
Spin coater	28	83	22	84	26	80	27	75
Mask aligner	28	90	30	98	44	115	37	74
Thermal furnace	16	61	21	63	24	58	22	45
Wire bonder	2	6	17	38	16	31	11	27
RIE	2	10	33	100	45	94	36	61
Sputter	NA	NA	20	61	36	55	26	47
E-beam	NA	NA	19	70	22	71	21	47
MEMCAD	NA	NA	7	81	12	50	12	25
PECVD	NA	NA	NA	NA	26	48	23	33
ICP etching	NA	NA	NA	NA	10	50	12	25
Dicing saw	NA	NA	NA	NA	NA	NA	9	31
MATFOR	NA	NA	NA	NA	NA	NA	3	3
Total	114	561	207	1202	323	1033	305	964

The Nanotechnology Experiments (I) and (II) courses focus on specific topics, such as fabrication of micro structures, bio-channels, fabrication of one dimensional nano-materials, synthesis of the nano carbon tubes and nano wires, characterization field emission of nano-particles, etc., as listed in Table 5. The success of the hands-on experiment courses can be credited to the newly established the Center for Nano-Science and Technology at NTU. With strong support from the university, the modern laboratory instruments were able to be centralized in the dedicated class room for student's access.

Table 5 Course outline for "Nanotechnology Experiments (I) and (II)" (3 semester credit hours each)

Experiment title	In charge department
Computer simulation of nano-scale structure and energy state	Center for Condensed Matter Sciences (CCMS)
Zero order nano-scale material fabrication for suspended metal nano-particles	Dept. of Chemistry
Zero order nano-scale material fabrication for semi-conductor nano-particles	Dept. of Chemistry
MEMS fabrication and thin film mechanical property measurements using AFM	NEMS Research Center
Polymer nano-particle synthesis and properties characterization	CCMS
CVD Synthesis of one-dimension nano-materials	CCMS
Optical film synthesis from nano silicon oxide particles	Dept. of Chemical Engineering
Sol-gel SnO_2 fabricated semi-conductor film for chemical sensing	Dept. of Chemical Engineering
Nano wires fabrication and measurements	Dept. of Physics
Scanning Tunnel Microscopy experiments	Dept. of Physics

4 PROGRAM ASSESSMENT AND CONCLUSIONS

The curriculum program is entering its third year now. Nearly 100 students every semester were admitted to join the program. As of 2004, the total enrolment in the program exceeds 500 students coming from 26 departments across six colleges of the university as shown in Table 6. Interesting thing is that one law school student approved in the program.

The program evaluation was coherently considered at beginning of the curriculum planning. Quantitative assessment in the form of course evaluation was taken for all courses through internet access. An advisory committee of the curriculum was formed at early planning of the program, and committee meeting has been held at least twice a year for program review and strategy adjustment. Student evaluation was conducted at the end of the semester. All students were asked to conduct the evaluation form without their name marked. Table 7 listed the evaluation outcomes and students' comments about the "Introduction of Nanotechnology".

With the total of over 500 students enrolled in this program, Up to now, there are a total of 14 students who have completed the curriculum requirement. Less than 3% of the total enrolment reaches the completion of the curriculum. Many courses' modification have been made to meet the inter-disciplinary nature with other related courses. The advisory committee reviews and positively provides guide lines to the program administration.

Strategic partnership with the surrounding universities is also encouraged to alliance with local industries and other research organizations to jointly develop teaching resources and technical specialties. These research associates include Sinica Academy, Industrial Technology Research Institute, Chung-Shan Institute of Science and Technology, Precision Instrument Development Center, etc. In average, a total of 39-45 professionals were invited to offer lectures at university and more than 1000 person-time students were benefited each year. In the past two years, efforts on training seed teachers for the kindergarten to 12th grades have now received concrete achievements. Framework in the national wide nanotechnology education has also been established. Interaction and communication mechanisms with students and partner schools and industries have been set up through web-based internet. News, activities, course information, instruments, and achievements were posted and periodically updated on one website.

In summary, this article addresses the nanotechnology curriculum which was established in response to the rapid growth of human resource needs in micro-system and nanotechnology in Taiwan. In compliance with the multi-disciplinary nature of the technology, the design principle, focuses, contents, goal and current status of the nanotechnology curriculum were addressed.

Table 6 Statistics of student distribution in the program at National Taiwan University

National Taiwan University College/Department Enrolments in Nanotech program	**Y2001 2nd term**	**Y2002 1st term**	**Y2002 2nd term**	**Y2003 1st[t] term**	**Y2003 2nd term**	**Total [sum in college]**
A. **College of Engineering**						**[407]**
Civil Engineering	14	28	6	12	3	63
Mechanical Engineering	30	35	30	26	7	128
Chemical Engineering	26	18	7	5	11	67
Eng. Science and Ocean Eng.		16	20	7		43
Materials Science and Eng.	1	5	15	46	2	69
Environmental Engineering	9	5	1	1		16
Biomedical Engineering					1	1
Building and Planning					1	1
Applied Mechanics	5	6		6	1	18
Polymer Science and Eng.		1				1
B. **College of Electrical Engineering and Computer Science**						**[53]**
Electrical Engineering	4	20	11	13		48
Computer Science and Information		1				1
Opto-Electro Engineering	1	1		1		3
Electronic Engineering		1				1
C. **College of Science**						**[39]**
Chemistry		2		3	1	6
Physics		9	10	7	3	29
Geosciences		1		2		3
Botany			1			1
D. **College of Life Science**						**[12]**
Life Science				1		1
Bio-Industrial Mechatronics Eng.	2	1		2	3	8
Agricultural Chemistry					1	1
Forestry		1		1		2
E. **College of Management**						**[1]**
International Business		1				1
F. **College of Social Sciences**						**[1]**
Political Science	1					1
Total (24 departments across 6 colleges)	93	152	101	133	34	**513**

Table 7 Course evaluation outcomes for "Introduction of Nanotechnology" in 2003

Evaluation Item	Very positive (%)	Positive (%)	Fair (%)	Not positive (%)	Negative (%)	No comment (%)
A. course planning						
1. are you satisfied outside lecturers who are non-NTU faculty?	29	62	9	0	0	0
2.are you satisfied the overall arrangement of the course?	18	66	14	1	0	1
B. Teaching						
1. are you satisfied the overall teaching performance?						
◦ lecturers from NTU	31	59	9	0	0	1
◦ lecturer from other universities	23	65	11	0	0	1
◦ lecturers from industry	12	61	15	1	0	1
2. are you satisfied the teaching attitude?						
◦ lecturers from NTU	44	49	7	0	0	0
◦ lecturer from other universities	32	58	10	0	0	0
◦ lecturers from industry	31	57	11	1	0	0
3. are you satisfied the lecturers' specialties?						
◦ lecturers from NTU	46	47	6	1	0	0
◦ lecturer from other universities	40	53	6	1	0	0
◦ lecturers from industry	41	49	8	2	0	0
C. experiments and fab visit						
1. are you satisfied arrangement of the industry fab visit?	22	39	33	4	0	2
2. are you satisfied the number of times for fab visits?	13	39	39	6	1	2
D. administration						
1. are you satisfied the administration assistance of THE course ?	10	46	37	4	1	2
2. do you agree taking this course will be helpful for your future career?	18	44	35	2	0	1
E. Comments and suggestions for the course Too many students in the class, the learning may be a question. Suggest limiting the class size down to below100 students. Suggest more industry fab visits. Suggest to invite more speakers from industry						

ACKNOWLEDGEMENTS

Authors acknowledge support of the program by the Ministry of Education, Taiwan, ROC, and numerous faculty members and staff from NEMS Research Center, Center for Nano-Science and Technology, National Taiwan University who have contributed for nanotechnology education program.

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