AC 2007-1806: INTRODUCING MICRO/NANOTECHNOLOGY EDUCATION WITHIN THE INDUSTRIAL AND SYSTEMS ENGINEERING CURRICULUM

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Introducing Nanotechnology Education within Industrial Engineering Curriculum

1. Introduction

Industrial engineering (IE) programs are concerned with the design, improvement and installation of integrated systems of people, materials, information, equipment and energy [1]. An important part of industrial engineering curriculum focuses on product/process design and optimization. The undergraduate course work within the manufacturing curriculum at North Carolina A&T State University focuses on hands-on laboratory machine-tool instruction, computer aided design & manufacturing and systems levels production control. Specifically, we offer three sequential manufacturing courses namely; INEN 246: Industrial Production Processes, INEN 324: Computer Aided Design and Manufacturing, INEN 446: Automation and Production Systems. In addition, students interested in manufacturing specialization chose a technical elective INEN 632: Robotics Systems and Applications towards their BS degree. The INEN 246: Industrial Production Processes course covers traditional manufacturing processes including metal casting, forming, material removal and joining. This is followed up with computer aided design and control of machine tools within the INEN 324: Computer Aided Design and Manufacturing course. Finally, students are instructed on the automation and integration of manufacturing systems within INEN 446: Automation and Production Systems. The manufacturing coursework within our IE program is focused around macro and meso scale manufacturing technologies. However, with the ever shrinking sizes of devices, there is a renewed interest to study manufacturing processes at the micro and nano scales. Given the rapid advancement in the micro and nano processes it is imperative that we educate our students in manufacturing processes along varying length scales. Over the past year we have introduced micro and nanotechnology modules within two courses. This includes a mandatory undergraduate level course (INEN 324: CADCAM) where micro and nano manufacturing modules are developed. In addition, we have supplemented a combined graduate level and senior elective course (INEN 632: Robotics Systems and Applications) with modules in MEMS (micro-electro-mechanical systems), micro and nano robotics. In this paper we discuss our experiences and insights drawn by introducing supplementary learning and experimental content within traditional IE courses. Key features include, teaming undergraduate and graduate students in multidisciplinary projects, exposure of these students to state-of-the-art micro and nano research facility at NC A&T SU, outreach to local schools and lectures to K-12 and prospective college students. Student feedback coupled with ABET course evaluation indicates a favorable response and strong demand for the introduction of Nano and Micro technologies within a traditional IE program.

2. Introduction of Micro and Nano Modules within Manufacturing Curriculum

Nano and micro modules were introduced in two courses described below. Each of these modules was instructed over a three week period with two lecture series of 1hr 15 mins per week. For each of these modules the instructor covered core concepts of nanomaterials and unique phenomena at the nanoscale during the first week. This extended the basic physics and chemistry courses taken by the Industrial engineering students specifically towards nanotechnology applications. The authors believe that instead of offering standalone nano and micro technology modules, it was best to integrate them as addendum to existing courses. This is because many Industrial engineering students are unfamiliar with these state-of-the-art fields. The approach is to gradually introduce students to nano/micro technology as extensions to existing advanced manufacturing courses. Further, after sufficient awareness is generated, the author plans to introduce standalone courses at both senior (undergraduate) and graduate levels.

INEN 324: Computer Aided Design and Manufacturing
Student Enrollment: Senior: (30-50) and (Graduate: 5-10)
Course Description: This course covers Computer-Aided Design (CAD), Computer-Aided Manufacturing (CAM), and their integration. Topics include computer-aided design, process planning, Numerical Control (NC) programming and operation, Group Technology (GT), rapid prototyping, integrated production planning and control, and integrated manufacturing data systems. Design projects are required.

Integration of micro/nano manufacturing concepts (INEN 324):
We introduced micro and nano manufacturing concepts as an addendum to the existing course. Students were given a primer on length scale effects at the nano and micro level. Further they were instructed on micro fabrication techniques such as lithography, LIGA, Deep Reactive Ion Etching, Wet & Dry Micromachining etc. In addition, they were also introduced to latest nanomanufacturing techniques such as Nanopen, E-beam lithography, Nanoimprint lithography etc. At the end of the lecture series, students were assigned an in-class assignment to identify real-world products using the micro and nano manufacturing processes.

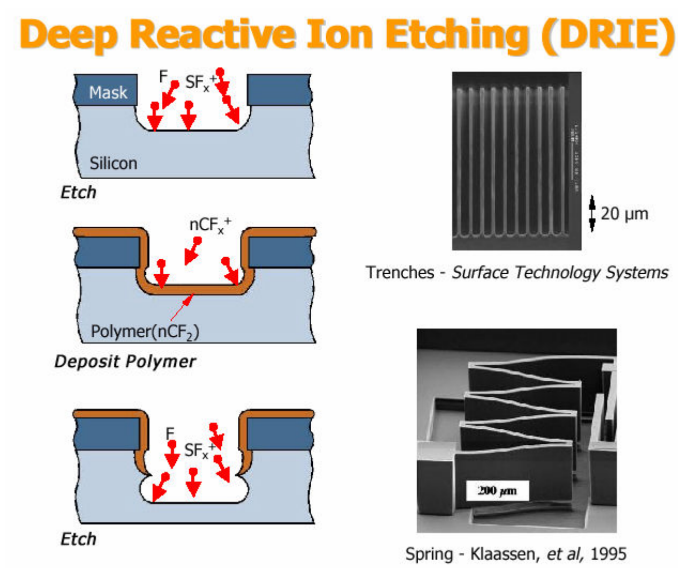


Figure 1. Deep Reactive Ion Etching Microfabrication Process [2]

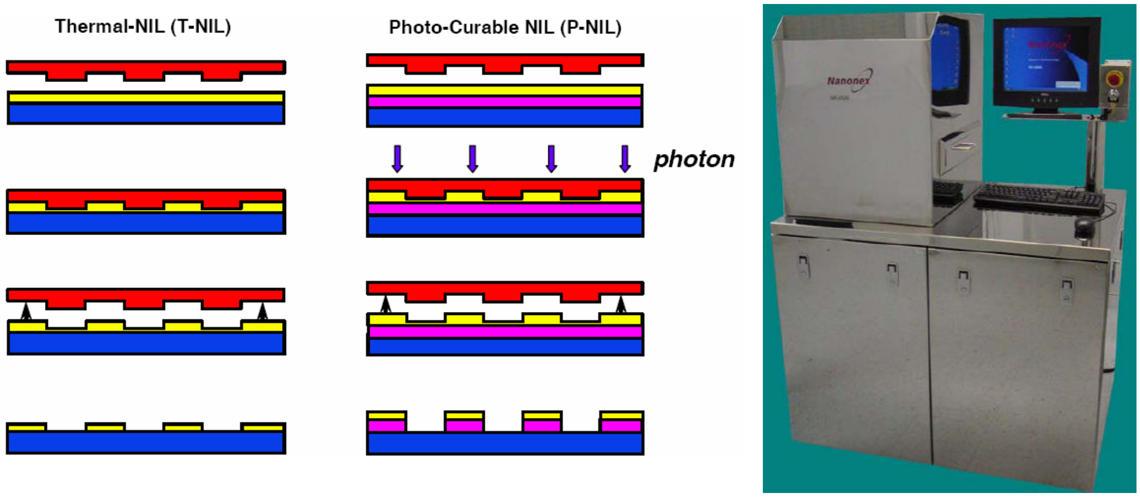


Figure 2. Nanonex thermal nanoimprint (T-NIL) and photo-curable nanoimprint (P-NIL) (left), Nanonex NX-2000 machine (right) [3]

INEN 632: Robotics Systems & Applications
Student Enrollment: Senior Elective (15-25)/ (Graduate: 5-10)
Course Description: This course addresses the design, analysis, implementation, and operation of robotics in production systems. End effectors, vision systems, sensors, stability and control off-line programming, and simulation of robotic systems are covered. Methods for planning robotic work area are emphasized. Design projects are required.

Integration of Micro/Nanotechnology Concepts (INEN 632):
After covering core concepts of robotic systems, the instructor conducted lecture series on micro and nano robotics. Current developments in microelectromechanical systems (MEMS) and their use in micro robotic devices were introduced. Students were updated with micro robot components, subsystems and their applications. Future ideas on bio-based nanorobots in medicine were introduced. Students were assigned an in-class assignment which required them to come up with components and subsystems that would go into a nanorobotic system. In this course students had an opportunity to delve into the futuristic research topics spurring interest into graduate education.

Figure 3: Eye catching example of an ant holding a LIGA fabricated gear in its claw (MEMS component [4]

3. Research component within micro and nano technology modules

Students were introduced to current research in inkjet based micro fabrication. Multiphysics model results (as shown in Figure 4) from the author's research in direct-write based micro/nano fabrication were introduced and disseminated as research readings [5].

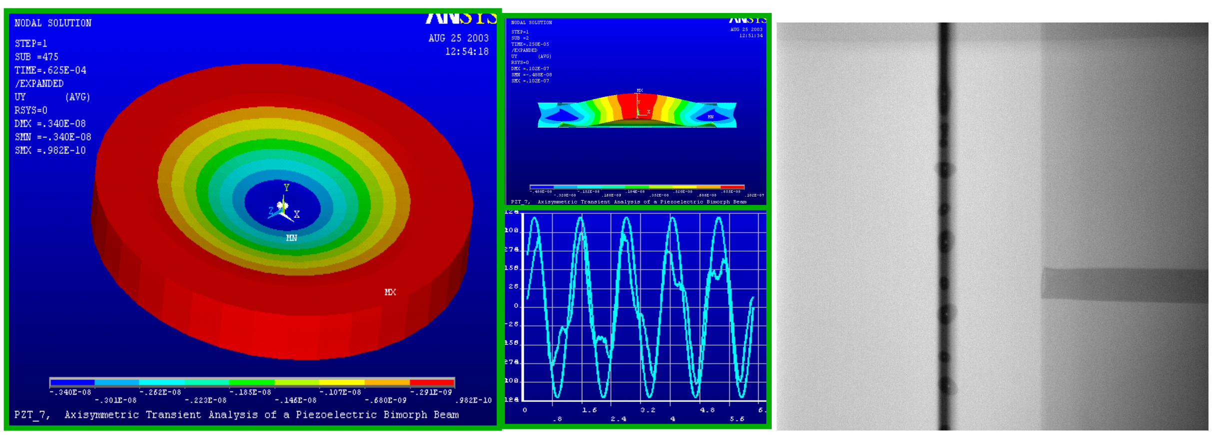


Figure 4: (Left) 3D deformation of Piezoelectric Bimorph Disc in micro fabrication process. (Center-top); Exploded 2D view piezoelectric deformation at disc center (Center-bottom); Superimposition of excitation voltage and PZT displacement (Right); Ultra-high speed photography of micro-drop formation (Exposure: 10μs) [5]

Students were also exposed to micro-capsule based drug delivery and regenerative tissue scaffolds using customized microfabrication process (shown in Figure 5) [6].

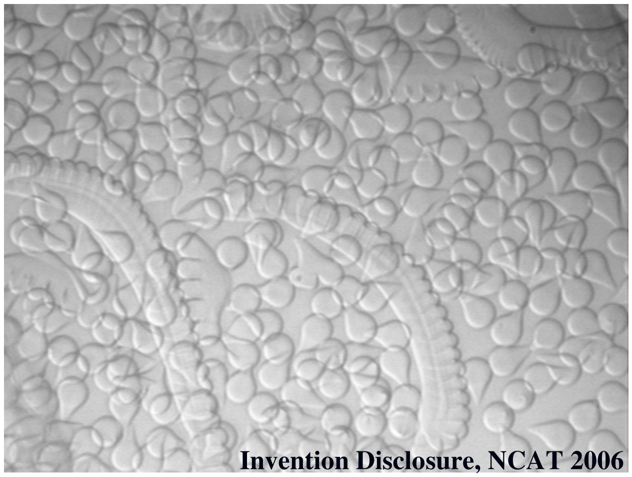


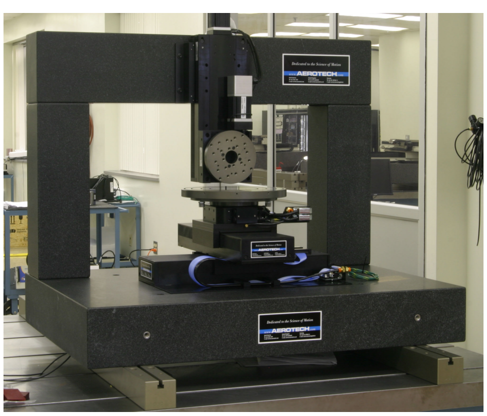
Figure 5: Micro capsules and tissue scaffolds using inkjet based microfabrication process [6]

4. Laboratory component within micro and nano technology modules

The instructor organized laboratory tours to the Center for Advanced Materials and Smart Structures (CAMSS) at NCA&TSU. This type of a hands-on-experience enabled students to appreciate the use of state-of-the-art equipment (ultra high speed photography, precision micro position stage, customized inkjet system) which are involved in the development of micro and nano fabrication processes.

(a)

(b)



(c)

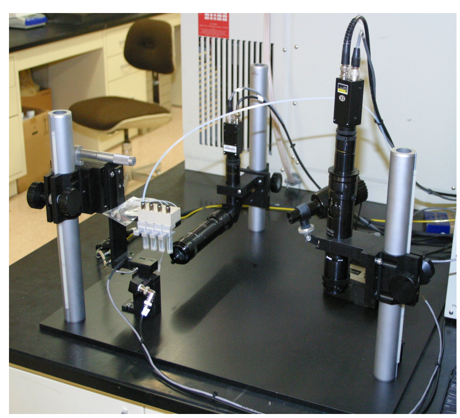


Figure 6. Infrastructure exposure to students (a) Ultra high speed camera (b) 5-axis precision stage (c) Customized inkjet system

5. Outreach of micro and nano technology modules through K-12 education

Engineer Starter's Program: In collaboration with faculty at the CAMSS, the authors organized a summer camp for the Engineer Starter's Program (ESP) at NCA&TSU. In the Engineer Starter's Program, about fifty highly motivated minority high-school students (grades 9-12) within the Greensboro area are identified, trained and directed towards an undergraduate degree in engineering. The authors coordinated their activities with the Engineer Starter's Program and planned non-residential summer camp. Students were introduced to the micro and nano concepts with a presentation. They were assigned homework task to list miniaturized components that go into devices being used in their daily life. Further the authors coordinated a laboratory visit to CAMSS and demonstrated micro-drop fabrication with assistance from graduate students.

6. Evaluation of Micro and Nano Course Modules

The micro and nano lecture modules were evaluated based on two measures namely; (1) Pre and post learning surveys and (2) NCA&TSU teaching evaluations for the two courses. The learning survey included a total of 7 multiple choice questions. The surveys were administered for a population size of 25 students from the INEN 324: Computer Aided Design and Manufacturing course. The questions probed the student's knowledge on concepts taught during the lecture series. Table 1 shows the question category for each question number. Figure 7 shows the correct response to each question before and after the lecture series. As seen from the graphs below, the students assimilated relevant advanced manufacturing concepts during the lecture series.

In addition to the above surveys, we looked at instructor teaching evaluation for both the courses. For INEN 324: CADCAM the instructor received a teaching evaluation score of 4.3 out of 5, while for INEN 632: Robotics Systems & Applications the score was 4.6 out of 5. Both of these teaching evaluation scores were above the average score of 4.1 out of 5 for the College of Engineering at NCA&TSU. Student feedback via written comments indicated a strong request for these modules to be integrated as part of the regular course offering in the following years.

Table 1: Question Categories for Nano & Micro Manufacturing Survey

No.	Question Category
1	Basic micro and nano science
2	Application of manufacturing process towards MEMS
3	Nanomanufacturing process
4	Equipment and process conditions needed for micro/nano manufacturing
5	Industrial engineering technique used to optimize a nanomanufacturing process
6	Application of nanomanufacturing
7	Semiconductor fabrication using micro/nano manufacturing

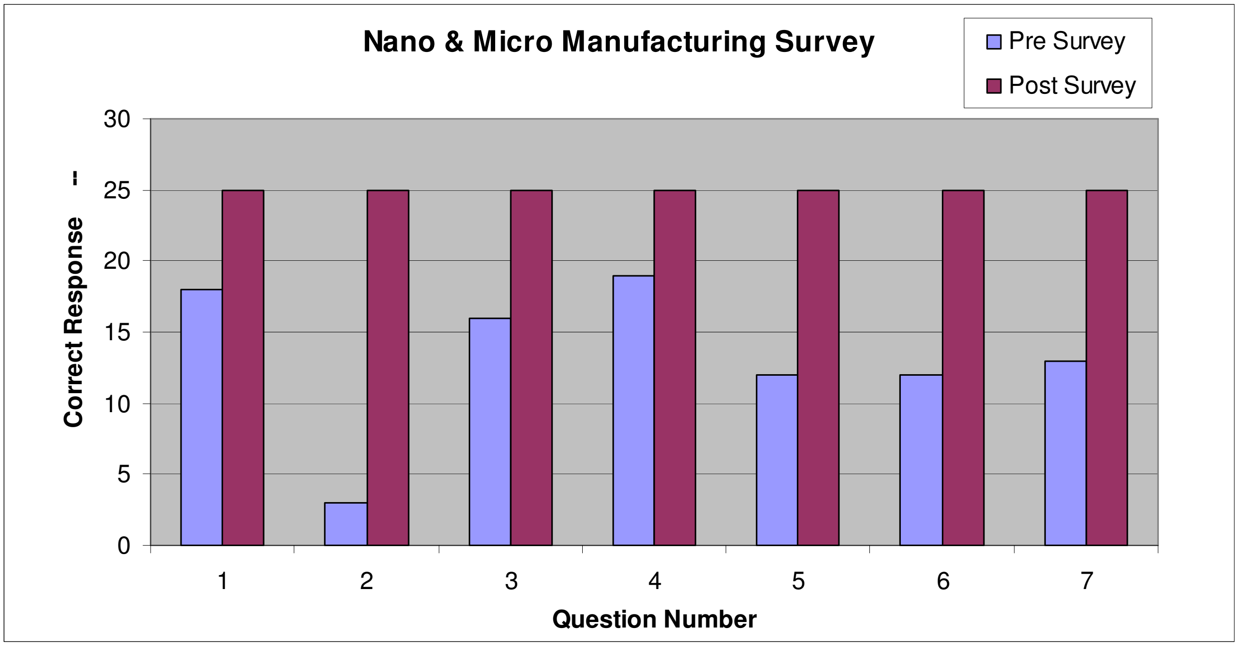


Figure 7. Correct Responses to survey questions Pre and Post of lecture series

A two sample T-test for correct responses on the seven questions for the Pre and Post survey (shown in Table 2) was conducted. This test was conducted to assess the improvement in knowledge before and after that introduction of the nano/micro manufacturing modules. Based on the extremely low P-value of the T-test, it is evident that there exists significant difference between Pre and Post survey results. This means that students had higher correct responses to survey after attending the lecture sessions indicating that the introduction of Nano and Micro manufacturing modules enhanced student knowledge in this area.

Table 2: T-test for correct response on seven questions for the survey

Sample	**Sample Size**	**Mean**	**StDev**	**SE**
1 (Pre Survey)	25	3.12	1.24	0.25
2 (Post Survey)	25	5.88	1.01	0.20

Difference = μ (1) - μ (2)
Estimate for difference: -2.76
95% CI for difference: (-3.40329, -2.11671)
T-Value = -8.64, P-Value = 0.000

7. Impact of Micro and Nano Course Modules

After offering the pilot modules within the industrial engineering curriculum student interest within the nano and micro areas of manufacturing was elevated (as seen from the evaluation results). At least 6 undergraduate students per course were interested in research experiences with the authors at federally supported nano science/engineering centers in NC A&T SU. Some of the interested students will be undergoing summer research experience with the author at the NSF - Nanoscale Science and Engineering Center at NCA&TSU. In addition, senior students were highly motivated to pursue graduate studies in the nanotechnology field. The author has recruited two seniors who will be joining his nano-manufacturing research program in Fall 2007. Based on the positive response for these module offerings, the PI will be offering stand-alone nanotechnology courses at the senior/Masters level in the coming year. He is currently, offering a Ph.D. level special topics course INEN 885: Nano and Bio Manufacturing in Spring 2007. Introducing nano and micro technology modules within the IE curriculum is an important avenue for instilling interest, educating and inspiring students to pursue higher degrees and career paths in nanotechnology field. This will expand the possible career options for Industrial engineering students.

8. Conclusion

Nano and micro manufacturing modules were introduced within the industrial engineering curriculum at NC A&T SU. Pre and post surveys were used as evaluate the benefit of the nano and micro manufacturing modules. Statistical analysis results indicated that students had higher correct responses on post survey versus the pre survey results. This indicates enhanced understanding of nano and micro technology after being introduced to the modules. In addition higher teaching evaluation results coupled with student feedback indicated a strong demand for these modules to be integrated into manufacturing courses. However, in order to fully assess the effectiveness of these modules, we need to continue to follow student performance and impact by collecting longitudinal data for analysis. Nevertheless, it is safe to say that the introduction of these modules is promising. The authors believe that the introduction of similar nano/micro technology modules can benefit other Industrial Engineering programs within the country.

9. Acknowledgement

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10. References

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