

PROJECT BASED COURSE ENABLED NANOTECHNOLOGY EDUCATION FOR SENIOR LEVEL UNDERGRADUATE AND GRADUATE STUDENTS

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ABSTRACT

NSF funding was obtained to nucleate nanotechnology curriculum and start a senior-level nanotechnology course cross-listed in the Mechanical Engineering and Electrical Engineering department. The key components are implementation of lectures integrated with hands-on laboratory experience, research seminar and evaluation. Laboratory projects of nanofabrication of MOS capacitor and nano-structured solar cell were designed for engaging undergraduate and graduate students. The research seminars from prestigious institutions broadened students' knowledge base and created potential networking opportunities. The assessment of course materials and master's understanding was evaluated by surveys and direct observations of student performance. In spring 2020, 20 students were evaluated and 14 students attended the survey, where 12 of them are undergraduate students. Statistical data from survey demonstrated that graduate students responded overall high rate for all of the course materials and undergraduate students gave high rate for majority of course materials except thermal evaporation fabrication project. A significant standard deviation for rating of thermal evaporation fabrication process indicated that practical engineering projects are challenging for some undergraduate students. Further efforts will be adopted to form a pipeline teaching approach that graduate students will lead fabrication process projects and share their nanofabrication experiences with undergraduate students to enhance learning outcome.

Keywords: Nanotechnology, Laboratory Experience, Seminar, Evaluation

1. INTRODUCTION

Nanotechnology and nanoscience represent a wide range of fields which involve structures, devices, and systems with unique properties and novel functions due to 1–100 nm scale [1]. Nanotechnology contributes to almost every aspect of science and technology, including engineering, physics, materials science, chemistry, biology and medicine [1]. Nanotechnology and nanoscience are one of the most advancing technology of the 21st century and hold tremendous growth opportunities

[1]. Recently, the national nanotechnology initiative (NNI) have supported efforts to increase participation in nanotechnology R&D from underrepresented groups[2]. Many undergraduates, especially at minority-serving institutions, are expected to gain remarkable career and academic opportunities after getting adequate training in the field of nanoscale fabrication and measurements[2]. Typically, undergraduate research experience-based training only benefited few students (<1% of engineering students at our institution). Only a few faculty mentors are available to work on the nanotechnology-related research projects with students. To overcome this challenge, we obtained NSF funding to nucleate nanotechnology curriculum and started a senior-level nanotechnology elective course cross-listed in the Mechanical Engineering and Electrical Engineering department. Since 2017 this course has been over-subscribed. Recent NSF Center for Nanoscale Research and Education (CNRE) has provided enhanced laboratory components to give an in-depth understanding of nanotechnology to senior-level undergraduates and graduate students enrolling in recently approved MS and Ph.D. programs. This paper will describe the impact and design of the nanotechnology course funded by NSF. The goal of this course is to provide engineering students with depth, breadth, and diversity of nanotechnology knowledge required to prepare for challenges area such as CREST-funded nanoscale electronics for next-generation computers, metal additive manufacturing, and nanomaterials-based energy systems, nano-medical devices, batteries, fuel-cells and various societal and environmental challenges with potential use of nanotechnology[3].

There have been education importance to include nanotechnology in the engineering curriculum [3-8]. Raza etc reported a first year seminar nanoengineering course with small class setting, providing students to be exposed to the bottom-up approach and nanotechnology applications[3]. Balasubramanian etc, implemented a spiral curriculum model into a freshman engineering course at Virginia Tech for the first time[4]. Uddin etc proposed a methodology to integrate nanotechnology education into mainstream undergraduate engineering curricula[5], which include multiple level courses for

sophomore, junior/senior and graduate students[5]. Mohammad etc reported a comparative study of the nanotechnology courses from several universities in the USA, UK, Singapore, Australia and Malaysian[6]. Three junior-level lecture courses and a senior/graduate laboratory course have been introduced by Morris etc [7]. The novel aspects by Morris etc includes results of student and external evaluation [7]. Yolcu etc conducted an exploratory study of undergraduate engineering students' awareness, exposure and motivation towards nanotechnology and found male students have more awareness toward nanotechnology than female students [8]. Although growing interest in nanotechnology education, nanotechnology course has not yet been fully included in the undergraduate curriculum. In addition, these reported courses [3-8] mainly focused on first or second-year undergraduate students. Hence, there are great needs to develop a comprehensive nanotechnology education for senior/graduate students in order to facilitate their success and leadership in rapidly evolving nanotechnology field. Herein, we illustrate the multidisciplinary nanotechnology course we developed to lay foundation of curriculum development to meet these needs. The multidisciplinary nanotechnology course combined key education modules with use of nanotechnology application laboratory at UDC for multiple-level student education to achieve effective learning outcomes. The education modules are novel and crucial, which include 1) a series of lectures integrated with hands-on laboratory experience, where laboratory projects were designed with multiple-level experience; 2) research seminar; and 3) evaluation to assess learning outcomes of minority undergraduate and graduate students.

2. Development of Nanotechnology Learning Module

All materials and methods that have been used in the work must be stated clearly. Subtitles should be used when necessary.

The nanotechnology course is multidisciplinary, usually students from electrical engineering and mechanical engineering. Majority of students are senior students, approximate 15% of students are junior students and about 15% of students are graduate students. The prerequisite for the nanotechnology course are physics II and lab, two semester of general chemistry. The all of students meet prerequisite and all of the junior students have took physical electronics which form solid foundation to take the upper-level nanotechnology course. In the following, we will demonstrate teaching modules which effectively integrate these multi-level students.

2.1 Integration of Lectures with Hands-on Laboratory activities

Learning module integrated a series of lectures with hands-on laboratory activities, where the hands-on laboratory activities cover lecture theory to achieve effective and efficient learning outcomes for multiple-level students. Table 1 shows topics that lectures covered and

nanotechnology laboratory activities that require applications of those topics are also provided in Table 1.

As shown in Table1, students exposed to various nanofabrication facility and lecture combined with hands-on laboratory activities provide opportunity for students to use theory in practice, forming active learning approach. Due to lack of E-beam evaporator and reactive ion etching at nanotechnology application laboratory at UDC, students didn't have laboratory experience on them. However, videos about E-beam evaporation and reactive ion etching process and operation have been distributed to students in order to enhance their understanding of lecture materials.

Table1 Topics Covered by lectures and Laboratory Activities

Lecture Content	Laboratory Activates
Nucleation and Growth Kinetics	Covered by Thermal Evaporation and Sputtering Lab Experience
Photolithography: Photoresist and Mask	Covered by Photolithography Lab Experience
Photolithography: Exposure and diffraction and interference	
Photolithography: Mask Aligner	
Photolithography Process	
Vacuum and Plasma	Covered by Thermal Evaporation and Sputtering Lab Experience
Thermal Evaporator	Covered by Thermal Evaporation Lab Experience
E-beam Evaporator	Didn't Cover
Sputtering	Covered by Sputtering Lab Experience
Anisotropic and isotropic etching	Covered by Lift-off Process
Wet Etching	Covered by Lift-off Process
Reactive Ion Etching	Didn't Cover
Life-off and Etch-back Process	Lift-off Process was covered by lab activity

These laboratory activities were designed for undergraduate and graduate students respectively.

Undergraduate students' lab project is to fabricate MOS capacitor by lift-off process. Graduate students' lab project is to fabricate a nano-structured solar cell. Table 2 shows MOS capacitor and nano-structured solar cell project process.

Table 2 MOS capacitor and nano-structured solar cell projects.

MOS capacitor	Nano-structured solar cell
Photolithography to form nanopattern on SiO ₂ /Si substrate	Photolithography to form nanopattern on SiO ₂ /Si substrate
Thermal Evaporation to deposit Al film	Sputtering to deposit solar Materials
Sputtering to deposit Ni film	Thermal Evaporation to deposit Al film
Wet etching and lift-off process to form MOS capacitor	Wet etching and lift-off process to form nanostructured Schottky diode of a nanostructure solar cell.
Microscope to observe nanopattern and final device.	Microscope to observe nanopattern and final device

Each process including lab experiment procedures has been designed and described in the lab project and assigned to students before lab activities. Figure 1 shows that student worked in photolithography project. Students work in a team to perform photolithography, thin film deposition, wet etching processes under teaching assistant and instructor assisting and supervising. It been found that lab project description and teaching assistant and instructor assisting and supervising greatly enhance students' learning effectiveness.

2.2 Research Seminar

Other class activities include research seminar in nanotechnology area. We organized about five research seminar related to nanotechnology each semester. Guest speakers are arranged with scientists and engineers from prestigious institutions and national lab that are involved in nanotechnology. Some of these research seminars are "The Role of the National Nanotechnology Initiative and How to Engage" from National Nanotechnology Coordination Office, "A.I. in Materials Science Opportunities for Autonomy and Challenges of Trust" and "Ultrathin Magnetic Films for Future Nanoelectronics"

from National Institute of Standards and Technology. Undergraduate students are encouraged and graduate students are required to attend three research seminars each semester. These research seminars not only broadened the knowledge base of students and also created networking opportunities with strategically invited experts to benefit minority students' learning. It has been found that questions from students demonstrated students' highly engaging and actively learning seminar materials in nanotechnology.

2.3 Evaluation

As part of the assessment activities for nanotechnology, a student survey has been implemented since the Spring 2020. Twenty students participated in the course, all of them are minority students and the majority of them belonged to African-American minority group. In the survey, The maximum of score is 5, representing "excellent", score of 4 represents very good understanding level, the minimum of score is 1, representing "don't understand". 12 of 17 undergraduate students attended survey and 2 of 3 graduate students responded survey in Spring 2020. Table 3 shows the average score (AV.S) and standard deviation (STDEV) of undergraduate student (UG) and graduate student (G) evaluations for their understating of course materials. Table 3 shows average score (AV.S) and standard deviation (STDEV) of undergraduate student (UG) and graduate student (G) evaluations.

As shown in table 3, the survey evaluated various phases of course materials and project and determined the extent to that the course modules foster students' understanding of nanotechnology knowledge. As shown in Table 3, undergraduate demonstrated average score is higher than 4 in the majority of course materials except thermal evaporation fabrication process project. For thermal evaporation fabrication process project, a wide range of rated scores was found in undergraduate students' evaluation, where three of students gave the score below 3, three students rated 4 and other six students rated the highest score of 5. The wide spectrum of rated scores in evaporation fabrication process project indicates that practical efforts are much more challenging than thermal evaporation theory for part of undergraduate students, and reflects the importance of implementing hands-on projects with nanotechnology laboratory experience. The result disclosed that lecture materials integrated with corresponding laboratory projects deepened undergraduate students' understanding of course materials and promoted them to gain specialized nanotechnology skills.

Observed from graduate students' responses, overall rating for all of the course materials belongs to the high level, indicating the quality and effectiveness of lecture deliverables combined with implementation of laboratory projects for graduate students. Findings from these formative evaluations are fed back to form a continuous improvement teaching strategies. In order to increase undergraduate students' hands-on lab experiences and in the meantime enhance graduate students' comprehensive ability, graduate students will lead fabrication process projects and share their nanofabrication project experiences with undergraduate students during lab session,. It will inevitably form an effective teaching environment to ensure high quality and effective course deliverables.

Table 3 Average score (AV.S) and standard deviation (STDEV) of undergraduate student (UG) and graduate student (G) evaluations

Understanding of Course Materials	AV.S of UG	STDEV	AV.S of G	STDEV
Photolithography Theory	4.3	0.89	4.5	0.71
Photolithography process procedures	4.42	0.67	4	0
Plasma	4.3	0.65	4	0
Sputtering theory	4.3	0.49	4	0
Sputtering fabrication process	4.2	0.75	4	0
Thermal evaporation theory	4.17	1.0	4	0
Thermal evaporation fabrication process	3.9	1.56	4	0
E-beam evaporation theory	4.17	0.71	4	0
E-beam evaporation fabrication process	4.3	0.77	4.0	0
Wet etching	4.25	0.45	4.5	0.71
Dry etching such as reactive ion etching	4.08	0.67	4.0	0

Lift-off process	4.25	0.75	4.0	0
Nanofabrication application in industry or research area	4.25	0.87	4.5	0.71

Table 3 further revealed undergraduate and graduates students rated high score for nanofabrication application in industry or research area. Both of undergraduate and graduate students increased awareness about wide applications of nanotechnology and nanotechnology course, which equipped them well for further pursuing academic and/or industrial development in this field.

The nanotechnology course greatly benefits students' interdisciplinary research activities. The nanotechnology lecture integrated with course modules such as laboratory, research seminar etc encourages them to begin their research projects early in their college years. Those undergraduate students who are interested in the current NSF funding nanotechnology research projects at UDC can begin their research projects early and be smoothly integrated into these research projects based on knowing much of the background information and experiences by taking the nanotechnology course. For examples, some of undergraduate students who completed the nanotechnology course performed undergraduate research under supervision by Center for Nanotechnology Research and Education (CNRE) faculties at UDC. The nanotechnology course greatly enhanced graduate students' research capability by deepening their knowledge, generating new mindset and well training specialized nanotechnology skills. Thus, nanotechnology course promoted graduate students to seamlessly integrate these knowledge into the challenging research projects and facilitated their success in these research projects such as the CREST-funded nanoscale electronics for next-generation computers, metal additive manufacturing, and nanomaterials-based energy systems.

3. CONCLUSION

The multidisciplinary nanotechnology course with education modules of lectures integrated with hands-on laboratory experience, research seminar and student evaluation was successfully deployed through the use of nanotechnology application laboratory at UDC. Lab projects of nanofabrication of MOS capacitor and nano-structured solar cell were performed by junior/senior undergraduate students and graduate students respectively. The lab projects were well designed and covered majority of lecture materials. Students exposed to practical

environment and applied theory into engineering projects, fostering active and deep learning of course materials and promoting them to gain specialized nanotechnology skills. It is found that research seminars given by guest speakers from prestigious institutions and national lab broadened the knowledge base of students and also created networking opportunities with the invited experts. Evaluation survey assessed the extent to that course modules facilitate students' understanding of nanotechnology knowledge. Evaluation results demonstrated that graduate students responded overall high ratings for all of the course materials and undergraduate students rated high for majority of course materials except thermal evaporation fabrication process project. The rating for thermal evaporation fabrication process project has a large standard deviation, indicating practical effort is much more challenging for some of undergraduate students. Evaluation survey further revealed that both of undergraduate and graduate students are well aware of import applications of nanotechnology in industry and academy. The nanotechnology course encouraged undergraduate students to start their research projects in their college years and motivated undergraduate and graduate students to be smoothly integrated into NSF-funding nanotechnology research projects-next-generation computers, metal additive manufacturing, and nanomaterials-based energy systems. Future work will include forming a pipeline teaching approach that graduate students will lead fabrication process projects and share their nanofabrication project experiences with undergraduate students for effective learning outcome. The oral presentation will be included in near future in order to enhance students' communication skills.

ACKNOWLEDGEMENTS

This work was supported by grants from the National Science Foundation CREST: Center for Nanotechnology Research and Education at UDC (Award 1914751).

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