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An Integrated Multidisciplinary Nanoscience Concentration Certificate Program for STEM Education

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Integration of nanoscience and nanotechnology curricula into the College of Science, Mathematics, and Technology (CSMT) at the University of Texas at Brownsville (UTB) is reported. The rationale for the established multidisciplinary *Nanoscience Concentration Certificate Program* (NCCP) is to: (i) develop nanotechnology-relevant courses within a comprehensive Science, Engineering and Technology curriculum, and, to offer students an opportunity to graduate with a certificate in nanoscience and nanotechnology; (ii) to contribute to students' success in achieving student outcomes across all college's majors, and, improve the breath, depth and quality of science, technology, engineering and mathematics (STEM) graduates' education; (iii) through NCCP, recruit certificate- and associate-degree seeking students into four year programs in engineering and physical sciences. A long-term goal is to develop an ABET accredited bachelor program in nanoscience. This program is expected to reach out to a large group of undergraduate students in a coordinated manner, enhance students' knowledge and skills, as well as facilitate efforts of individual faculty members in STEM education. The UTB NCCP is supported by the NSF NUE program, under which we are developing and offering seven upper-level interdisciplinary undergraduate courses. These courses and program are assessed and evaluated.

Keywords: Nanoscience, Nanotechnology, Undergraduate Program, NSF NUE, STEM Curricula.

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1. INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) fields have become increasingly vital to US national economic competitiveness and growth. Students graduating in the STEM fields have traditionally been in high demand due to their training, expertise and skills. The National Science Foundation (NSF) and United States Department of Labor (DOL) statistics show this historical trend, projecting significant increases in demand for the next decade regardless of the prevailing economic conditions (National Science Foundation, 1997, 2001). Long-term strategies to maintain and increase workers' living standards and promote opportunity require coordinated efforts among public, private and not-for-profit entities to promote innovations and prepare qualified professionals in the STEM fields. There is a significant demand for knowledgeable and skilled professionals needed by high-technology industries. This demand must be met to guarantee US economic growth and technological superiority. Correspondingly, significant efforts must be focused to support emerging nanoscience and nanotechnology enterprises, the growing nanotechnology industry, front-end technologies, enabling products and emerging markets.

Multidisciplinary nanoscience, molecular engineering, microsystems and nanotechnology fields have experienced phenomenal growth in recent decades. Recent fundamental, applied and experimental developments have notably contributed to this progress and have motivated further educational developments and enhancements in nanoscience and nanotechnology. According to the US National Nanotechnology Initiative, the goals

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are to develop and sustain educational resources and a skilled workforce while supporting infrastructure and tools to advance nanotechnology National Nanotechnology Initiative Strategic Plan (2007). There exists a critical need to supplement traditional intra-disciplinary training with interdisciplinary nanoengineering curriculum to address the needs of both emerging nanotechnology enterprises and rapidly growing nanotechnology industry Evans et al. (2003). These prominent trends identify many desirable changes in undergraduate science, engineering and technology curricula, education and training (National Nanotechnology Initiative Strategic Plan, 2007; Evans et al., 2003; Fincher, 2009; Jackson, 2003; Lyshevski et al., 2006, 2011; Lyshevski & Fuller, 2007; Martirosyan et al., 2012). Development of nanoscience research and educational programs is one of the goals of the College of Science, Mathematics, and Technology (CSMT) strategic plan which addresses the need for this fast-growing emerging area, and provides students with additional opportunities to succeed in their careers after graduation. Faculty in three different departments (Physics, Chemistry and Engineering) are involved in nanoscience related research resulting in publications in prestigious journals, external funding and students involvement in undergraduate research. Implementation of the College's strategic plan to incorporate nanotechnology into the University of Texas at Brownsville (UTB) undergraduate curriculum is coordinated by a strong interdisciplinary team of faculty members which are highly experienced in nanotechnology areas and have diverse backgrounds. As a result of these across-the-college efforts, multidisciplinary undergraduate *Nanoscience Concentration Certificate Program (NCCP)* was developed and implemented in the CSMT at UTB.

2. TARGET AUDIENCE AND CHALLENGES IN NANOSCIENCE CONCENTRATION CERTIFICATE PROGRAM DEVELOPMENT

The common practice for approving new programs at higher educational institutions involve consistent internal and external justifications, national needs, proven impact on other institutional programs, academic rigor of the program, potentials for specialized accreditation, etc. (Roco, 2003, 2011). In case of regional comprehensive universities, like UTB, the success of the program development often depends on the socio-economic environment of the region that determines social, racial, and ethnic composition of the university's student body Romig et al. (2007). We develop academic minor or certificate programs of study. The college's composition of majors within the programs accredited by ABET, state and other agencies may be decisive factors for the program's enrolment and ultimate success. Furthermore, students traditionally establish career path preferences (Roco, 2008, 2012; NSTC/NSET, 2012; Yueh & Sheen, 2009).

The University of Texas at Brownsville (UTB) is located at the southernmost tip of Texas at the juncture of the US-Mexico border and the Gulf of Mexico. With a regional population of more than 90% Hispanics, UTB is one of the leading institutions in the nation in educating minority students in the areas of science, technology, engineering and mathematics. The CSMT offers eight Bachelor of Science degrees and four Master of Science programs. The number of students enrolled in all programs (including associate degrees, certification, bachelor degrees and master degrees) for the Fall 2012 semester was 1,907. This represented a 20% increase over the prior year's enrolment according to the University's Office of Data management, Academic Advising and Office of Graduate Studies. Of that number, 1,506 students were pursuing a bachelor's degree. The reported number of baccalaureate majors by department: Biological Science 776 (52%), Chemistry 52 (3%), Computer and Information Science 127 (8%), Engineering 256 (17%), Engineering Technology 37 (2%), Environmental Science 65 (4%), Mathematics 142 (9%) and Physics & Astronomy 51 (3%).

The College is well positioned to make significant efforts in meeting the demand for STEM graduates to support the emerging technologies, which are enable the economic growth. The CSMT academic programs in engineering, engineering technology, physics and astronomy, biological science, chemistry, computer science, environmental science, and mathematics provide avenues for cross disciplinary training and research experience for student scholars. The emerging areas of renewable energy production and nanoscience impact each of the programs of study. However, students in engineering physics, physics, engineering technology and chemistry programs form the major target audience for minors and certificates in nanoscience.

The nanosciences program may also play a pivotal role in successful career paths for biology students (Yueh & Sheen, 2009; Nichol & Hutchinson, 2010). The Office of Health Professions Careers, a part of the CSMT, estimates that of the 776 declared Biological Science majors, 80% have intent to prepare for careers in medicine, dentistry or some other healthcare related field. Unfortunately, for the overwhelming majority of these students, their intent to become doctors never materializes because of the highly competitive nature of medical schools. These students need to have alternative career paths. Successful completion of a nanoscience certificate program will allow biology students, a group which constitutes a majority of the CSMT majors, to explore other successful career inroads. This exploration may result in enrolling in an interdisciplinary degree with a strong component in bioengineering related areas and applications of nanoscience to medical and pharmaceutical studies Roco (2008).

In this section we will discuss challenges we faced in the process of this program development. Following the national trend to contain the cost of education, the Texas Legislature passed a statute that expects students to graduate within 120 credit hours with the exception of engineering and teacher preparation degrees, where slightly higher amount of credit hours toward graduation is allowed. From the program development perspective, nanoscience certificate courses should not significantly increase the number of semester credit hours towards graduation for participating students. A nanoscience course should be accepted as an alternative to courses in the standard curricula of participating majors.

This challenge was amplified by specialized accreditation requirements for the ABET accredited Engineering Physics Program and pending accreditation from the American Chemical Society for the Chemistry Program. The need to be prepared for the MCAT exam also influences the decision of biology students to enrol in a nanoscience certificate program. While elaborating on the challenges related to biology students, we will also demonstrate how nanoscience programs positively impact the quality of education experienced by participating majors from other degree programs such as physics, chemistry and engineering. We elaborate on challenges pertaining to specialized accreditation in the sections related to engineering and chemistry components of the nanoscience certificate program.

A recent preliminary study of a select group of students with both high GPAs and high motivation was conducted by the CSMT's Office of Health Professions Careers. Results indicate that students may experience some challenges in the physics component of the MCAT exam. Listed from the least challenging to the most challenging are the following areas of physics: Electronic Circuit Elements; Force and Motion, Gravitation; Translational Motion; Fluids and Solids; Equilibrium and Momentum; Work and Energy; Electrostatics and Electromagnetism; Sound; Waves and Periodic Motion; and Light and Geometrical Optics.

Analysing nanoscience curriculum, examining the courses, evaluating students needs and expertise, as well as assessing student's knowledge and training, it is wound that irrespective of students major or intended post graduation careers, the certificate program contributes to students an overall knowledge generation, use and retention. For the evaluation purposes, we use scale from 0 to 8 (maximum). The course components receive: Electronic Circuit Elements-4; Force and Motion, Gravitation-3; Translational Motion-4; Fluids and Solids-5; Equilibrium and Momentum-3; Work and Energy-4; Electrostatics and Electromagnetism-4; Sound-4; Waves and Periodic Motion-4; Light and Geometrical Optics-4. Since the authors evaluated the contribution of only their own courses to the areas of expertise related to physics listed above, it could be stated that the level of contribution is very high. Thus, both physics faculty members rated the highest score potential contribution of the physics related nanoscience curriculum classes to six out of ten physics areas listed above. The result of this study could be extrapolated to all majors of participating students. The nanotechnology curriculum has a strong potential to reinforce the breath, depth and quality of education for all majors participating in a nanoscience program. The nanoscience courses contributed to the following student learning outcomes established for the biology majors irrespective of their chosen career path:

(i) Discuss, both orally and in writing, the relevance of new research findings;
(ii) Statistically analyse and interpret research data;
(iii) The graduates able to design experiments with appropriate controls, and to conduct original research in a biological discipline;
(iv) Discuss, both orally and in writing, the relevance of their research data to the original hypotheses and to the general field of interest;
(v) Propose ways to advance knowledge in the biological science.

3. CERTIFICATE PROGRAM

The structure and flowchart of the nanoscience concentration program at the UTB is outlined in Figure 1. The *NCCP* includes the following seven new undergraduate nanoscience courses:

- *Introduction to Nanoscience (PHYS-3301)*;
- *Engineering of Nanomaterials (ENGR-3312)*;
- *Nanofabrication and Nanoelectronics (ENGR-4311)*;
- *Introduction to Bio-Nanotechnology (PHYS-4301)*;
- *Environmental Nanotechnology (ENVR-4303)*;
- *NanoOptics (PHYS4302) and*
- *Capstone Design (PHYS-4303).*

To be awarded a Certificate in Nanoscience and Nanotechnology, students must complete 12 credit hours of the aforementioned nanoscience courses. The overall goal of the certificate program is to coherently educate and cohesively train highly-skilled and knowledgeable students in nanoscience and nanotechnology with applications. This program is designed to address the needs for an interdisciplinary undergraduate education at UTB and nationwide. Our program extends beyond traditional courses within disciplines, which are taught by various departments.

Undergraduate students, including underrepresented minorities, are educated and mentored within interactive-learning sessions, capstone-centric research projects and knowledge-enabling assignments. Faculties from all participating departments developed courses and course materials. Our long-term goal is to establish a practical, modular, scalable, transferrable, sustainable and implementable educational STEM platform in nanosciences, engineering and nanotechnology. The framework for our

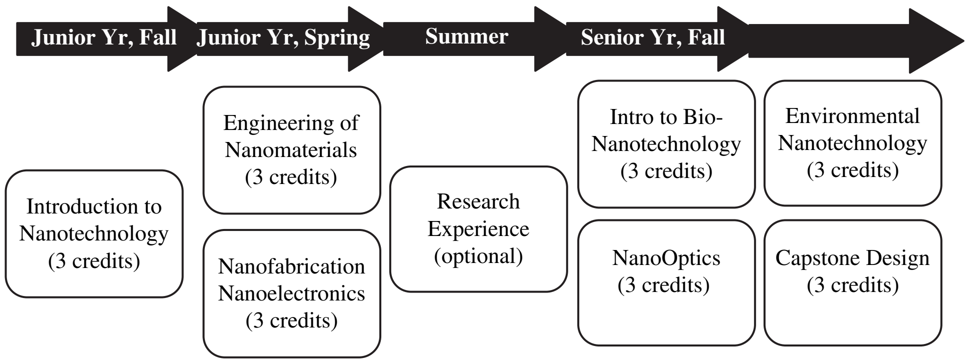

Fig. 1. The structure and flowchart of the Certificate Program in Nanoscience and Nanotechnology at the UTB.

program is designed to sustain a coherent program collaborating with undergraduate curriculum committees from the participating departments, e.g., Physics and Astronomy; Engineering; Technology; Chemistry and Environmental Science and Biology.

The *NCCP* meets the overall as well as specific learning and professional objectives and criteria of departments, college, university and ABET. Students may graduate with a BS degree and a Certificate in Nanoscience and Nanotechnology without increasing the required number of courses or credit hours. All students may take the developed courses to fulfill the program requirements within their departments. The established courses expose students to the nanotechnology areas as part of integration of nanoscience in UTB's undergraduate programs. This enables the STEM education endower, and, prepares students for emerging nanotechnology markets, industry trends, advanced research and enabling technology.

The *NCCP* provides an opportunity for undergraduate students to obtain knowledge, expertise, skills and training in nanoscience and nanotechnology while they are completing the requirements for their bachelor degrees. There are mechanisms for recognizing and rewarding students who obtain the broader education, as they become leaders in nanoscience and nanotechnology after graduation. The *NCCP* is an efficient and effective inroad to nanoscience and nanotechnology for students studying in a wide range of disciplines. The program is designed to enrich the research experience, increase the breadth of training, and expand the scholarly credentials of undergraduate students. At the time of graduation, the student's transcript will reflect certification that the student has completed the 12 credit hour requirements in nanoscience and nanotechnology. Students in the *NCCP* have access to a wide range of opportunities through our various programs including scholarships, summer research, nanotechnology-relevant conference, travel awards, college seminar program, and other activities. Summer research opportunity is open for students who are involved in the nanoscience program through our REU program. A "*Nanotechnology Mini-Conference*" is our annual meeting with poster sessions where students present their work to other students, professionals, faculty and industry representatives. The program hosts events such as workshops on writing papers to help students with issues of academic and professional development. In the college seminar program, students are invited to listen to presentations of top scientists working in nanoscience. Travel awards provide $1,000 to support students attendance at national conferences to present their research.

4. NANOSCIENCE COURSES

UTB developed seven elective undergraduate courses, which cover major aspects of nanoscience and nanotechnology. These courses were coherently designed and optimized to ensure the overall learning objectives while avoiding duplication of course materials. The consecutive courses are developed upon the foundation, knowledge and coverage of prerequisite courses. *NCCP* courses are supplemented with nanotechnology online laboratory exercises designed to familiarize students and scholars with cutting-edge research. This facilitates broader educational and professional developments.

4.1. Introduction to Nanoscience (PHYS-3301)

The *Introduction to Nanoscience* course is the first course introducing undergraduate students to the fundamental concepts underlying core nanotechnology. The course is centered on conventional classroom instruction supplemented with online laboratories and exercises by using University of Houston Nanofabrication Facility. The following topics are covered: introduction of nanostructures; fundamentals of quantum mechanics; overview of nanodevices and materials; bottom-up and top-down approaches; fabrication at nanoscale; nanoscale metrology and characterization techniques and tools.

4.2. Engineering of Nanomaterials (ENGR-3312)

The main objective of this course is to introduce various types of nanomaterials, nanostructures, their properties, characterization techniques, engineering applications and synthesis methods which are used in nanotechnology fields. Structural defects, purification techniques, and functionalization of nanomaterials and structures are discussed. Some introduced topics are outlined properties of various types of nanomaterials (C, ZnO, Si, Si_2O, SiC, Pt, Ag, Pb, Ag_2Ga and Al_2O_3) and nanostructures (nano-spheres, tubes, wires, platelets, ribbons, needles, clays, hybrids and nanocomposites). Atomic structures and properties (e.g., mechanical, thermal, electrical, magnetic, chemical and optical) are discussed.

4.3. Introduction to Bio-Nanotechnology (PHYS-4301)

The Introduction to Bio-Nanotechnology course is designed to assist UTB students in learning the fundamentals and cutting-edge nature of new and emerging multidisciplinary science, which either applies nanotechnology to living systems or makes use of the biological structures to create novel materials. This course introduces concepts in nanomaterials and their use with bio components to synthesize and address lipids, carbohydrates, proteins, and nucleic acids; cell structure and cell division, information methods in a cell immunology (antigens, antibodies, immune response).

4.4. NanoOptics (PHYS4302)

This course introduces students to general concepts of nanophotonics. The rapidly evolving new field within physics/engineering is focused on studies of interaction of light with matter on the nanometer scale. The course consists of lectures and laboratory exercises that involve computer modeling of photonic crystals, waveguides, and micro resonators.

4.5. Nanofabrication and Nanoelectronics (ENGR-4311)

The aim of the course is to provide knowledge of fabrication and characterization of nanostructures, which are used in nanoelectronics. The focus is centered on modern material processing used in nanofabrication. The course is based on conventional classroom instruction supplemented with laboratory exercises. It covers the following topics: Review of fundamentals and principles of major lithography technologies for devices and materials nanofabrication; Basics of clean-room design, safety, and classification. Unidirectional and non-unidirectional clean rooms will be discussed with an emphasis for semiconductor nanotechnology.

4.6. Environmental Nanotechnology (ENVR-4303)

The Environmental Nanotechnology course introduces the fundamentals of nanoscience and covers the properties of nanomaterials and their impact on the environment. This course covers fabrication technologies, characterization, and measurement of nanomaterials. Topics of particular interest include *clean* nanotechnologies for environmental quality, nanotechnologies in the energy industry, and the transport and fate of nanostructures in the environment. Environmental Nanotechnology is designed to take students from the introductory principles of nanoscience to a broader and deeper level of understanding of nanomaterials, their applications and possible toxicological impacts.

4.7. Capstone Design (PHYS-4303)

As part of the nano concentration program, *NCCP* students choose from among several Capstone Design Projects in their senior year. In addition, *NCCP* students have the option to apply for the *NCCP Summer Research Experience* following the junior year. The research in nanotechnology fosters innovations and interdisciplinary cooperation. This atmosphere is also evidenced by the fact that UTB is the proud home of the Center for Biomedical Studies, the Center for Gravitational Wave Astronomy and the Rancho del Cielo Field Station funded by NSF and NIH. The goal of this course is to provide students with an opportunity to design, build, test and evaluate devices and systems, which incorporate features of nanotechnology. Students who have successfully completed the *Capstone Design* course are expected to demonstrate their ability to identify and formulate scientific, engineering and technological problems and apply nanotechnology to design, analyze and build nanotechnology-based systems. Students will improve their ability to design and conduct experiments, analyze and interpret data and will gain experience to function in multi-disciplinary teams and communicate effectively.

Students, who successfully complete *NCCP* are expected to meet the following course outcomes:

(1) Students skilled to apply the *first principles* of classical and quantum mechanics to *macroscopic* and *microscopic* systems;

(2) Students gained knowledge to nanoscale devices, materials and biological objects;

(3) Students were able to understand the need for transitioning to nanotechnology to enable device and materials performance and capabilities;

(4) Students analyzed core fabrication technologies and approaches to metrology at nanoscale;

(5) Students received hands-on expertise in state-of-the-art nanotechnology instrumentation and gained skills in data analysis.

The program unifies concurrent efforts in various disciplines and programs, which actively engage students in learning and research. The educational curriculum and courses balance the coursework in various aspects of science, engineering and technology. Our educational and scholarship initiative overcomes the boundaries between

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disciplines. The established program enables a focused collaboration among students and faculty working across different fields and different departments.

5. SPECIALIZED ACCREDITATIONS, STATE REQUIREMENTS AND *NCCP* DEVELOPMENT

One of the challenges in the process of *NCCP* development was to align *NCCP* curriculum and the Student Learning Outcomes with the requirements of accrediting agencies, such as ABET for engineering and American Chemical Society for the chemistry program. The alignment had to be done with a restriction on any substantial increase in the number of credit hours required for graduation. This challenge was addressed for the chemistry and engineering programs in a similar way by replacing some courses in the established engineering and chemistry programs curricula with *NCCP* courses. In both cases the main challenge is to ensure that the Student Learning Outcome are enabled.

5.1. Engineering Program

The Engineering program follow the *a–k* Student Outcomes recommended by ABET, http://www.abet.org/eac-current-criteria/. Two *NCCP* courses, out from six courses reported in Figure 1, are the technical electives for the Engineering Physics students. These courses are counted towards the program requirements. The additional courses are optional courses. The fundamental nanotechnology concepts and the experimental skills acquired by the students through nanoscience courses are tied to a two-semester-long "Senior Design Project" course offered to the Engineering Physics students. Regarding the Capstone Design course (PHYS-4303), required by *NCCP*, the Engineering Physics students can choose nanotechnology related senior design projects that will be made available to them during their senior year. Senior Design I & II will be substituted as the Capstone Design course for *NCCP*.

As a result of this two-way substitution, the engineering students are able to receive nanotechnology certification by increasing requirements towards graduation by only one course.

There is a strong need for well educated nanoelectronics device design engineers, and therefore undergraduate-level training efforts are essential to meet future challenges related to nanotechnology. Integration of simulation based learning, (using simulation tools available at nanoHUB.org) helps the students to understand nanodevices concepts. On the other hand, Engineering of Nanomaterials is a complimentary course for Engineering Materials (ENGR-3405) and Introduction to Manufacturing Processes (ENGR 4407) that are junior and senior level courses for the Mechanical Engineering Physics students in the UTB Engineering Department. The Engineering Materials course is considered a pre-requisite for the Engineering of Nanomaterials. Lectures and lab demonstrations in the Engineering of Nanomaterials will be built upon basic science principles and the fundamental concepts that the students have learned in their Engineering Materials course.

Implementation of these nanotechnology courses will further strengthen the Engineering Physics curriculum and student outcomes, satisfying ABET accreditation requirements http://www.abet.org/appm/, http://www.abet.org/accreditation-criteria-policies-documents/. The approved substitution of the engineering curriculum courses described above ensure student outcomes meeting the ABET accreditation requirements. Each of these courses contributed to the following student outcomes:

(i) An ability to apply knowledge of mathematics, science, and engineering;
(ii) An ability to design and conduct experiments, as well as to analyse and interpret data;
(iii) An ability to identify, formulate and solve engineering problems;
(iv) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Through this certification program the commitment of the Engineering Department to engage in contemporary issues/technologies, continuous improvement, and lifelong learning (which are among the ABET accreditation criteria) will be addressed. Furthermore, course evaluation and assessment will determine the extent to which these student outcomes are achieved with the results used to improve the Program Educational Objectives, and its continuous improvement.

5.2. Chemistry Program

Students enrolled in the nanoscience concentration certificate program at UTB will be able to receive their certificate simultaneously with the Bachelor of Science in Chemistry with no more than 126 credit hours and increase hours toward graduation only by classes. Two chemistry courses, Chemistry Problems (CHEM 4320) and an upper level chemistry elective course, will be substituted with nanoscience courses "Introduction to Nanoscience" and "Environmental Nanotechnology" without jeopardizing the chemistry Student Learning Outcomes. This integration will also support current efforts in obtaining the American Chemical Society's program approval. Rigorous ACS accreditation standards and requirements emphasize conducting undergraduate research and writing scientific reports/publications, which are two major elements in nanoscience courses and the capstone project. Use of state-of-the-art instrumentation is funded and promoted in the nanoscience curriculum. Ultimately, students will be prepared for the future nanotechnology job market representing another program goal supported by the integration.

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The "substitute" nanotechnology courses contribute to the following Student Learning Outcomes adopted by the Chemistry Program:
(i) Demonstrate ability to successfully integrate chemical knowledge in undergraduate research projects;
(ii) Demonstrate a high level of problem solving, critical thinking and analytical reasoning ability in the context of their discipline;
(iii) Demonstrate proficiency in using computers to solve problems in chemistry;
(iv) Demonstrate their knowledge of current chemical and scientific theories and applications;
(v) Use modern library and database retrieval methods to obtain chemistry related information.

A similar strategy that helps to maintain other participating programs adopted the cap on hours towards graduation: (biology and environmental science). However, in this case the challenge was not amplified by accreditation requirements.

6. PEDAGOGY-TEACHING AND LEARNING STRATEGIES

There are a variety of teaching strategies which instructors use to improve student multidisciplinary learning in nanoscience and nanotechnology. Interdisciplinary courses and multidisciplinary curricula encompass a broad understanding of basic fundamentals in engineering and life sciences pertinent to nanoscience and nanotechnology. Interactive learning is the basis of courses Buehl (2008). The teaming arrangements and multidisciplinary teams provide a positive affect significantly benefiting both students and faculty.

Our courses are designed to actively engage students and create both a knowledge-centric and learning-centric environment inside and outside classes and formal course activities. These activities enable and encourage innovations, discovery and creativity. These are achieved throughout critical thinking, active and collaborative learning, discussion strategies, experiential learning, games-experiments-simulations, as well as problem-based and team-based learning and case studies. These learning strategies improve students understanding and empower knowledge retention. These features are very effective in developing higher order cognitive skills such as problem solving and critical thinking. These enhance the ability to intuit, clarify, reflect, connect, infer, and judge. These activities also engage students in discussions deepening their learning and motivation by encouraging students to develop their own views and hear their own voices. A good environment for interaction is the first step in encouraging students to talk. The role of the educator is to design "direct experiences" which include preparatory and reflective exercises. Experiments and simulations ensure a rich learning environment. Students use interactive tools such as the Internet, Smart phones, I-Pad and other appliances. Interactive technologies and simulations enable students to solve real-world problems in a safe environment, and, enable the learning process. Case studies Yin (2009) present students with real-life problems in nanoscience and nanotechnology, and, enable them to apply what they have learned in the classroom to actual engineering problems. It is found that case studies also motivate students to develop logical problem solving skills and empower group interaction skills during study of "Introduction to Nanoscience" course. Students identify problems, analyze possible alternative actions and provide solutions with a rationale and substantiation.

The courses are developed to teach using problem-based active learning techniques combined with interactive computer-aided instructional delivery, interactive techniques and advanced multimedia technologies. The homework assignments and student projects foster greater inclusion of active learning within the developed activities. This creates, promotes, and supports viable learning environment and scholarship. Our modular courses ensure team-teaching, adaptability, flexibility and student-faculty research opportunities across disciplinary boundaries.

We developed and instituted a proven problem-based learning and hands-on teaching approach in order to accelerate learning and training empowered by project-centric courses. This hands-on platform caters to the learning styles of all students. Our interactive laboratories enable advanced analysis, facilitate enormous gains in productivity and creativity, integrate design, accelerate prototyping, advance innovative design and motivate students.

7. PROFESSIONAL DEVELOPMENT AND LEARNING ACTIVITIES

Various enabling professional development and learning activities, including seminars and workshops, are fostered through our long-term program. In particular: college research seminar; lectures and presentations by invited speakers; interactive on-line laboratory activities using University of Houston's Nanofabrication Facility; nanotechnology laboratory tours; colloquia and presentations on impact of nanotechnology and ethical issues such as military applications, national defense, security, ecology, public safety, market, sustainability and others, are implemented. Moreover, the following sources are also designed to enable students' professional development: databases for maintaining and sharing engineering and scientific discoveries, innovations and findings; reference and citation databases; communication, technical writing; coaching for oral presentations and posters; service and outreach activities; panel discussions; graduate education and research, and job searching, etc.; and resume and professional career development.

8. INTEGRATION OF RESEARCH AND EDUCATION

The College of Science, Mathematics and Technology has a strong record in providing research opportunities to undergraduate students during the academic year and summer. We will leverage the UTB NSF-, NASA- and NIH-sponsored centers for *Gravitational Wave Astronomy* and *Biomedical Studies*. Our program leverages existing research activities offering undergraduate students an opportunity to participate in advanced scholarship activities. Students can choose from various interdisciplinary capstone projects and may apply for a *Summer Research Experience Internship*. This *Research Experience Internship* and *Capstone Design* course enhance education and training through highly-innovative multidisciplinary nanotechnology-centric experience, learning, scholarship and outreach. During the *Annual Student Conference*, the senior students present their research, senior design projects and their findings. These results are presented to the faculty, invited guests, industry representatives, professionals, other students and the general public.

9. STUDENT RECRUITMENT AND SELECTION CRITERIA

The *NCCP* program is widely advertised within our college. We aim to recruit students by:

• Mentoring and advising engineering/science students on the *NCCP* opportunities during the freshman and sophomore years through information sessions;

• Using our academic and professional support activities, such as the *Monday Night Physics*, *Physics Summer School* and *Collaborative Learning Workshops* which encourage students to take advantage of the *NCCP*;

• Inviting freshman and sophomore students to the *NCCP* colloquia, workshops, presentations and conferences.

The *Academic Success Forums* and *Collaborative Learning Workshops* enable students to advance and succeed academically. The *Career Guidance* and *Career Success Forums* assist students to develop well-defined career goals and prepare themselves to achieve their professional goals. Research workshops, presentations and conferences provide all students within departments and colleges with inspiring opportunities in research and subsequent graduate education in nanotechnology and relevant areas. Enrollment in the program is selective and competitive. The selection is based on the academic performance and research promise. At the end of their sophomore year, students are required to submit their applications. Our program is integrated within the existing recruitment, retention and placement tools and schemes.

10. ASSESSMENT OF LEARNING

The specific, measurable, achievable, relevant and timely learning objectives describe significant and essential learning which students achieve and can effectively demonstrate at the end of a course and program. These learning objectives are used in the design of classes, laboratories, assignments, projects, restructuring course modules, designing courses and overall program developments. The learning objectives, assessment and evaluation of measurable outcomes are essential in our developments. Our model and platform Martirosyan et al. (2012) promises one to enable material delivery, advance student knowledge, improve skills, enable expertise, and ensure sufficient depth and breadth.

We used formal evaluation/assessment activities such as Exams, Quizzes, Homework Assignments, In-class Activities, Paper Reports, Class Discussion and Individual Presentations for assessing expected learning outcomes. The class participants were 37 college students who lacked experience in nanoscience and nanotechnology. They were recruited from the College of Science, Mathematics, and Technology at UTB, and they fulfilled a class requirement by participating in the study. The diagrams in Figure 2 show the undergraduate students body population data that were registered in Fall 2012 for Introduction to Nanoscience course Martirosyan (2013).

The following table demonstrates student work examples for assessment. The level of achievement was evaluated using the following scale: E–Excellent, G–Good, S–Satisfactory, N–Needs Improvement.

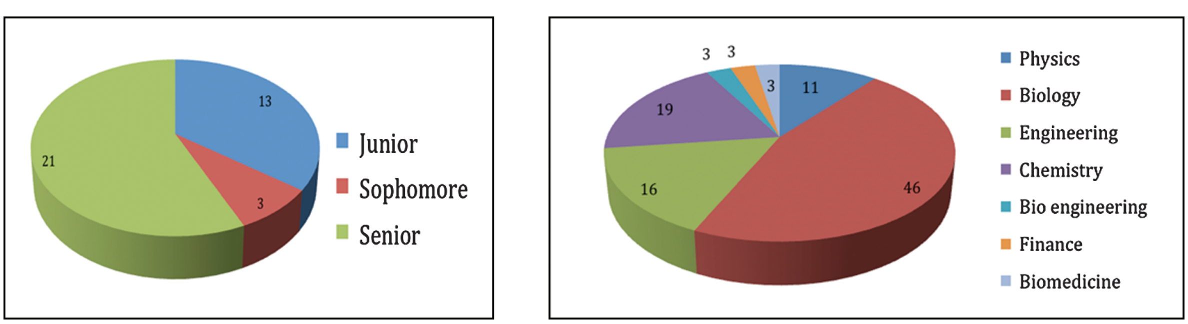

Fig. 2. The undergraduate students body population data (students registered for introduction to nanoscience course at Fall 2012).

Table I.

Artifact	Number of students who approached the problem N	S	G	E
Homework related to effects of reduced dimensions on physical and chemical properties of materials	2	8	17	10
Homework related to energy, wavelength and electron transitions	4	6	14	13
Quiz related to fundamentals of optical and e-beam lithography	3	7	18	9
Midterm exam	2	6	17	12
Final exam	2	4	16	15

35 students who have successfully completed "Introduction to Nanotechnology" met the following course outcomes:

• Students generated a knowledge-base on basics of device and materials physics in systems with reduced dimensions;
• Identified various types of nanomaterials, nanostructures, their properties, and applications;
• Understand the use of advanced characterization techniques and tools commonly used for testing and characterization of nanomaterials, nanostructures and nanodevices;
• Students gained basic understanding of the motivation behind the transitioning to nanotechnology with respect to device and materials performance;
• Understand the limitations and difficulties of working with materials and structures in nanoscale;
• Students learned basic understanding of modern fabrication technologies and approaches to metrology at nanoscale; Students received experience in utilizing state-of-the-art nanotechnology instrumentation and gain skills in advanced data analysis;
• Students received sufficient background knowledge and develop experimental skills to take on more advanced topics that will be presented in the following courses within the nanoengineering core. Understand the basics and fundamentals of most commonly used techniques for synthesis and processing of nanomaterials and nanostructures;
• Understand the characteristics of most commonly used carbon nanotubes (CNTs) growth techniques (chemical vapor deposition (CVD), laser ablation, and arc discharge) and identify their advantages and disadvantages;
• Understand the details of chemical vapor deposition technique for growing multi wall CNTs and identify the importance of growth parameters (e.g., carbon source feed rate, catalyst type and its size, carrier gas and its flow rate, reactor temperature and its pressure);
• Familiarize with scientific, ethical, societal, economical, environmental, and health issues that may arise from nanoscience and nanotechnology developments.

11. SUMMARY

The developed practical, modular, scalable, transferrable, portable and implementable educational platform in nanosciences, engineering and nanotechnology is presented. The consistently designed multidisciplinary nanoscience and nanotechnology curriculum targets undergraduate students across different departments. The *Nanoscience Concentration Certificate Program* seeks to provide students with the opportunity to learn nanoscale science, engineering and technology foundations while working with highly experienced and nationally recognized faculty. The designed nanoscience concentration certificate program enables in-depth training beyond what can be achieved by conventional stand-alone courses and activities.

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