The Development of a Comprehensive Undergraduate Degree Program in Nanoscale Science

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CNSE Oveview

- First college in the world dedicated to research, education, and deployment in the emerging disciplines of nanoscience, nanoengineering, nanobioscience, and nanoeconomics
- Over $5 billion in public and private investments
- More than 250 global corporate partners

CNSE Constellations

- The 48 faculty and instructors in the CNSE are partitioned among four “constellations”:
  - nanoscience
  - nanoengineering
  - nanobioscience
  - nanoeconomics
- The constellations were established primarily for promotion and tenure (CNSE Charter and By-Laws)
- Issues regarding curriculum are essentially independent of constellations
- This system was designed specifically to provide a highly interdisciplinary academic environment

Timeline of the CNSE Undergraduate Curriculum

- University at Albany – Board Of Visitors, Report of Observations and Recommendations, University at Albany, June 2006 -- the BOV called for the creation of the baccalaureate degree in Nanoscale Science
- Summer, 2006: The CNSE Curriculum Committee formed an *ad hoc* Subcommittee on Undergraduate Curriculum
- May 2007 – the *ad hoc* Subcommittee resolved to draft an undergraduate curriculum for the baccalaureate degree in nanoscale science
- May 2008 – approved by UAlbany and submitted to State Education Department
- June 2009 – approved by SED; first (honorary) Nanoscale Science degree awarded to SUNY Chancellor Nancy Zimpher
- Fall 2009 – 100-level undergraduate courses to be offered
- Spring 2010 – admission of students to undergraduate program and initiation of courses for majors

Admission and enrollment plans

- A five-year ramp-up of nanoscale science undergraduate enrollment is planned:
  - Year 1: 20 students
  - Year 2: 35 students
  - Year 3: 70 students
  - Year 4: 100 students
  - Year 5: 150 students
- Detailed plans for transfer and articulation are in place
- "Qualified UAlbany freshmen who demonstrate documented scholarly excellence and academic interest in nanoscale science or engineering may be offered an opportunity for direct freshman admission to the proposed CNSE Nanoscale Science undergraduate program"

Fundamental Principles Guiding the Development of the CNSE Undergraduate Curricula

- The curricula proposed are intended to attract and retain a significant portion of the undergraduate student population that is presently inaccessible to SUNY and most of the private institutions of learning in New York State
- This development is driven by the lack of interdisciplinary nanoscale science degrees that are sought by this rapidly growing sector
- Each curriculum represents a 132-credit program designed for completion in eight academic semesters and is consistent with the SUNY General Education Program requirements
- The outcome is a unique undergraduate experience that taps into CNSE's global academic leadership in nanoscale science and engineering to attract and educate a diverse and talented pool of qualified scientists and engineers at the baccalaureate level

Boundary conditions for the development of an undergraduate nanoscience curriculum

- Avoid an educational experience that is “a kilometer wide but a nanometer deep”
- Provide a foundation in the basic sciences: physical, chemical, biological (also mathematics)
- Allow the student to develop competency in their chosen area in nanoscale science
- Provide students with an intellectual foundation that will enable them to become lifelong learners
- Ensure an interdisciplinary learning experience
- Leverage the unique capabilities of the CNSE
- Prepare graduating students for a range of post-graduation options (workforce versus advanced academic degrees)

Basic Components of the CNSE Undergraduate Curriculum

1. Foundational Principles of Nanoscale Science
2. Core Competencies in Nanoscale Science
3. Concentrations in Nanoscale Science
4. Capstone Undergraduate Research/Design in Nanoscale Science
5. Survey, elective, and other courses
   - Nanotechnology survey
   - Nanoscale Science and Technology skills
   - Senior Seminar
   - Mathematics
6. General Education requirement

Foundational Principles of Nanoscale Science

- The course and laboratory* contents of the Foundational Principles components are designed to provide the core nanoscale science principles and intellectual "skill sets" required to ensure elementary understanding and basic knowledge of nanoscale science
  - NSCI 110 Chemical Principles of Nanoscale Science and Engineering I (4)
  - NSCI 112 Chemical Principles of Nanoscale Science and Engineering II (4)
  - NSCI 120 Physical Principles of Nanoscale Science and Engineering I (4)
  - NSCI 122 Physical Principles of Nanoscale Science and Engineering II (4)
  - NSCI 124 Physical Principles of Nanoscale Science and Engineering III (4)
  - NSCI 124H Physical Principles of Nanoscale Science and Engineering III (Honors) (4)
  - NSCI 130 Biological Principles of Nanoscale Science and Engineering I (4)
  - NSCI 132 Biological Principles of Nanoscale Science and Engineering II (4)

* ***laboratory concepts discussed later***

Laboratory examples for Foundations classes

NSCI/NENG 110, Project 2 – Nanoscale chemical analysis of porous nanomaterials

Reinforced topics from lecture

- Nanomaterials characterization
- Scanning electron microscopy (SEM)
- Kinetic theory of gas
- Equilibrium and monolayers
- Equilibrium constants
- Adsorption
- Adsorption isotherm
- Masses, moles, and numbers of molecules
- Free energy

Laboratory task outline:

Task 2.1 – Lab lecture and basic training

- Lab lecture and literature review
- Map out the experiment and predict results/understanding
- Basic training

Task 2.2 – SEM analysis of nanoporous materials

Task 2.3 – Quartz crystal microbalance mass uptake experiments

Task 2.4 – Gas adsorption and surface area analysis of nanoporous materials

NSCI/NENG 120, Project 2 - Nanoscale Force, Motion and Friction Lab

Reinforced topics from lecture

- Forces, acceleration
- Projectile motion
- Friction
- Motion
- RMS Roughness and Measurement
- Friction, static vs dynamic

Laboratory Outline:

macroscale laboratory

Task 2.1: Force, Motion and Friction in Everyday Life

- Measure distance steel balls with different masses travel
- Plot distance vs. mass. With expected result from derived equation of motion
- Measure Force of friction as a function of mass/normal force
  - Measure static frictional forces of wood block on bench for 3 different masses
  - Measure dynamical frictional forces of wood block on bench for 3 different masses
  - Plot frictional forces vs. normal force.
- Measure forces of friction for several different contact roughnesses
  - Measure static frictional force with constant mass and three different grits of sandpaper 60, 100, 200
  - Measure dynamical frictional force with constant mass and three different grits of sandpaper 60, 100, 200
  - Plot frictional force vs. roughness

nanoscale laboratory

Task 2.2: Nanoscale Force, Motion and Friction

- Introduction to the AFM, scanning and image acquisition
- Measurement of RMS roughness of three surfaces
  - Glass Slide
  - Mica or HOPG
  - Gold film on Glass Slide
- Measurement of frictional forces on AFM cantilever for the same surfaces
- Plot average frictional force vs RMS roughness

Preliminary estimate of resource needs

- Potential startup major equipment needs:

Item	Unit cost	Quantity	Total
Veeco atomic force microscope	$65,000	5	$325,000
Nicolet FTIR with thin film analysis accessories	$75,000	1	$75,000
Scanning electron microscope (JEOL Nanoscope)	$60,000	1	$60,000
Sputter coater	$30,000	1	$30,000
Veeco Dektak Stylus Profilimeter	$25,000	1	$25,000
Ocean optics compact spectrometer	$4,000	5	$20,000
Mass balances 0.001g readability	$1,000	5	$5,000
Analytical balance 0.01 mg readability	$4,000	1	$4,000
Spin coater	$4,000	1	$4,000
Total major equipment			$548,000

- Minor equipment, supplies and facilities easily drive this number to >$1M

Core Competencies in Nanoscale Science

- The course and laboratory contents of the Core Competency components are intended to impart sophisticated capabilities required for advanced, in-depth, study in nanoscale science
  - NSCI 220 Structure of Matter (3)
  - NSCI 220H Structure of Matter (Honors) (3)
  - NSCI 230 Thermodynamics & Statistical Mechanics for Nanoscale Systems (3)
  - NSCI 230H Thermodynamics & Statistical Mechanics for Nanoscale Systems (Honors) (3)
  - NSCI 240 Biochemical Principles for Nanoscale Science (3)
  - NSCI 300 Integrated Laboratory I (3)
  - NSCI 305 Integrated Laboratory II (3)
  - NSCI 350 Introduction to Quantum Theory for Nanoscale Systems (3)
  - NSCI 360 Nanoscale Molecular Materials and Soft Matter (3)
  - NSCI 410 Quantum Origins of Material Properties (3)

Concentrations in Nanoscale Science

- This component of each degree is comprised of specialized under-graduate coursework or individually-directed independent study in a specific nanoscale science concentration area
- Combined with upper level elective courses, this component of each degree permits a high degree of interdisciplinary instructional customization
- Currently there are three Technical Concentration areas:
  1. Nanoelectronics
     - NSCI 310 Nanoscale Surfaces and Interfaces (3)
     - NSCI 320 Advanced Physical/Chemical Concepts for Nanoscale Science (3)
     - NSCI 420 Electronic Properties of Nanomaterials (3)
     - NSCI 421 Nanoscale Electronic Devices (3)
     - NSCI 422 Concepts in Molecular Electronics (3)
     - NSCI 423 Magnetic and Spintronic Materials and Devices (3)
     - NSCI 424 Optoelectronic Materials and Devices (3)

Concentrations in Nanoscale Science (cont.)

2. Nanostructured Materials
   - NSCI 310 Nanoscale Surfaces and Interfaces (3)
   - NSCI 320 Advanced Physical/Chemical Concepts for Nanoscale Science (3)
   - NSCI 430 Nanoscale Physical Properties in Reduced Dimensions (3)
   - NSCI 431 Growth of Nanostructured Materials (3)
   - NSCI 432 Particle Induced Chemistry (3)
   - NSCI 433 Properties of Nanoscale Composite Structures (3)
   - NSCI 434 Nanostructural Characterization Techniques (3)

3. Nanobioscience
   - NSCI 240 Biochemical Principles for Nanoscale Science (3)
   - NSCI 330 Energetics and Kinetics in Nanobiological Systems (3)
   - NSCI 440 Biological Architectures for Nanotechnology Applications (3)
   - NSCI 441 Nanobiology for Nanotechnology Applications (3)
   - NSCI 442 Nanoscale Bio-Inorganic Interfaces (3)
   - NSCI 443 Biological Routes for Nanomaterials Synthesis (3)

Capstone Undergraduate Research/Design in Nanoscale Science

- This component of each degree entails 3 semesters of individually-directed independent research that will serve as an on-site internship within a true research environment that is conducive to innovation and discovery
  - NSCI 390 Capstone Research I. Introduction and Literature Review (3)
  - NSCI 490 Capstone Research II. Team Research and Project Review (3)
  - NSCI 492 Capstone Research III. Team Research and Final Report (3)
  - NSCI 493 Capstone Research III. Team Research and Final Report (Honors) (3)

The CNSE NanoFab: A Cutting Edge facility for Undergraduate Research Instruction

The proposed Nanoscale Science UG curriculum will coherently integrate and leverage CNSE's state of the art research facilities at each level to develop the essential interdisciplinary laboratory science, engineering, and design skills of our students

- Foundational Principles of Nanoscale Science → **Coordinated Laboratory Modules: Foundational Principle Illustration in Nanoscale Materials Systems**
- Core Competencies in Nanoscale Science → **Project-based Laboratory Learning: Computer control; Structure of matter, Adv circuits, etc….**
- Concentrations in Nanoscale Science → **Project, team-based Lab structure: Nanoelectronics (e.g. NW circuits), Nanobio, Nanostructure materials**
- Capstone UG Research-Design in Nanoscale Science → **Adviser-directed, capstone research in core concentrations (nanomat., nanoelectronics, nanobio)**

Capstone research experience

- Individually-directed independent research will serve as an on-site internship within a true research environment that is conducive to innovation and discovery
- Initial plans are to utilize the state-of-the-art facilities in the CNSE for the undergraduate capstone research experience
- Potential capstone research projects will draw on the rich environment of company partners on site in the CNSE
- Capstone projects have the potential to expose students to real-life problems
- The CNSE environment will provide enrichment to students who are pursuing either industrial careers or advanced degree options

Additional Courses for the Nanoscale Science Program

- Nanotechnology survey courses (6 credits)
  - NSCI 101 Nanotechnology Survey (3)
  - NSCI 102 Societal Impacts of Nanotechnology (3)
  - NSCI 103 Economic Impacts of Nanotechnology (3)
  - NSCI 104 Disruptive Nanotechnologies (3)

- Nanotechnology Science and Technology skills (6 credits)
  - NSCI 201 Computer Control of Instrumentation (2)
  - NSCI 202 Introduction to Nanoscale Engineering Design and Manufacturing (2)
  - NSCI 203 Advanced Circuits Laboratory (2)
  - NSCI 204 Finite Element Modeling (2)
  - NSCI 205 Numerical Simulation (2)

Additional Courses for the Nanoscale Science Program (continued)

- Senior seminar (1 credits)
  - NSCI 498 Current Topics in Nanoscale Science and Engineering (1-6)

- Mathematics (18 credits)
  - AMAT 112 Calculus I (4)
  - AMAT 118H Honors Calculus I (3)
  - AMAT 113 Calculus II (4)
  - AMAT 119H Honors Calculus II (4)
  - AMAT 214 Calculus of Several Variables (4)
  - AMAT 214H Honors Calculus of Several Variables (4)
  - AMAT 220 Linear Algebra (3)
  - AMAT 314 Analysis for Applications I (3))

General Education Requirements

- The General Education Program at the University at Albany proposes a set of knowledge areas, perspectives, and competencies considered by the University to be central to the intellectual development of every undergraduate
- Coursework is intended to provide students with a foundation that both prepares them for continued work within their chosen major and minor fields and gives them the intellectual habits that will enable them to become lifelong learners
- Courses within the program are designed not only to enhance students' knowledge, but to provide them as well with new ways of thinking and with the ability to engage in critical analysis and creative activity.
- The General Education Program at the University at Albany consists of a minimum of 30 credits of coursework in the following areas: disciplinary perspectives, cultural and historical perspectives, and communication and reasoning competencies

General Education Requirements

Requirement	Credits
Disciplinary Perspectives	
Arts	(min. 3 crs)
Humanities	(min. 3 crs)
Natural Sciences	(min. 6 crs)
Social Sciences	(min. 6 crs)
Cultural and Historical Perspectives	
U.S. Historical Perspective	(min. 3 crs)
Europe	(min. 3 crs)
Regions beyond Europe	(min. 3 crs)
Global and Cross-Cultural Studies	(min. 3 crs)
U.S. Diversity and Pluralism	(min. 3 crs)
Communication & Reasoning Competencies	(min. 1 course)
Information Literacy	(min. 1 course)
Oral Discourse	
Written Discourse	
Lower-level Writing	(min. 1 course)
Upper-level Writing	(min. 1 course)
Mathematics and Statistics	
One semester of collegiate study, or the equivalent, of mathematics at or above the level of pre-calculus and/or probability, statistics, and data analysis	
Foreign Language	
Two semesters of collegiate study, or the equivalent, of a foreign language	

B.S. in Nanoscale Science Semester-by-Semester Major Academic Pathway (MAP)

Year	Fall	Credits	Spring	Credits
1	NSCI/NENG 110 – Chemical Principles of Nanoscale Sci and Eng I[1]	4	NSCI/NENG 112 – Chemical Principles of Nanoscale Sci and Eng II[1]	4
	AMAT 112 or 118T – Calculus I	4	AMAT 113 or 119T – Calculus II	4
	NSCI/NENG 120 – Physical Principles of Nanoscale Sci and Eng I[1]	4	NSCI/NENG 122 – Physical Principles of Nanoscale Sci and Eng II[1]	4
	NSCI 101 – Nanotechnology Survey[1]	3	NSCI/NENG 102 – Societal Impacts of Nanotechnology[2,3]	3
	GE* (optional, if not taken, will be made up in future semesters)	3	GE (optional, if not taken will be made up in future semesters)	3
		15-18		**15-18**
2	NSCI 124 or 124T – Physical Principles of Nanoscale Sci & Eng III[1]	4	NSCI 230 or 230T – Thermo. and Stat. Mech. of Nanoscale Systems	3
	NSCI 20x – Science and Eng. Skills elective	2	AMAT 220 – Linear Algebra	3
	AMAT 214 or 214T – Calculus of Several Variables	4	NSCI 220 or 220T – Structure of Matter	3
	GE or liberal arts and sciences elective	3	NSCI 20x – Science and Tech. Skills elective	2
	GE or liberal arts and sciences elective	3	NSCI 20x – Science and Tech. Skills elective	2
			GE or liberal arts and sciences elective	3
		16		**16**
3	AMAT 314 – Analysis for Applications 1	3	NSCI 3XX – Technical Concentration Course	3
	NSCI 3XX – Technical Concentration Course	3	NSCI 360 – Nanoscale Molecular Materials and Soft Matter	3
	NSCI 350 – Intro to Quantum Theory for Nanoscale Systems	3	NSCI 305 – Integrated NanoLaboratory II	3
	NSCI 300 – Integrated NanoLaboratory I	3	NSCI 390 – Capstone Research I: Intro and Literature Review[4]	3
	GE or liberal arts and sciences elective	3	GE or liberal arts and sciences elective	3
	GE or liberal arts and sciences elective	3	GE or liberal arts and science elective (only if not taken in Semester #1)	3
		18		**15-18**
4	NSCI 410 – Quantum Origins of Material Behavior	3	NSCI 4XX – Technical Concentration Course	3
	NSCI 4XX – Technical Concentration Course	3	NSCI 4XX – Elective	3
	NSCI 4XX – Elective	3	NSCI 4XX – Elective	3
	NSCI 490 – Capstone Research II: Team Research and Project Review	3	NSCI 492 or 493 – Capstone Research III: Team Research and Final Report II[5,6]	3
	NSCI 498 – Seminar	1	GE or liberal arts and sciences elective	3
	GE or liberal arts and sciences elective	3	GE or liberal arts and science elective (only if not taken in Semester #2)	3
		16		**15-18**

What about biology?

- One of the more difficult problems in an undergraduate nanoscale science curriculum is including sufficient foundation in chemisty, physics and biology
  - NSCI 110 & 112 (Chemical Principles, 8 credits)
  - NSCI 120 & 122 (Physical Principles, 8 credits)
  - NSCI 130 & 132 (Chemical Principles, 8 credits)
- We could not incorporate all 24 credits and fulfill GenEd requirements within a 132 credit program
- Solution: NSCI 122 (Physical Principles II) and NSCI 124 (Physical Principles III) may be replaced by NSCI130 (Biological Principles I) and NSCI 132 (Biological Principles II) for students pursuing a nanobioscience concentration

Assessment

- A systematic, broad-based, and multi-pronged assessment is needed to determine progress towards and achievement of learning outcomes
- Proposed components:
  - course-embedded assessment metric (grading)
  - student-peer assessment metric (systematic oral and poster presentations by individual students or teams of students)
  - research project-based assessment metric (capstone research experience)
- These requirements satisfy SUNY requirements, but are not likely to give sufficient information for accurate assessment
- Greater depth and breadth in assessment function is “very likely” to be necessary for successful implementation

Honors Program

- Students may apply in the spring of the sophomore year to the honors program in either nanoscale science or nanoscale engineering
- The student must have an earned overall GPA of 3.25, with a GPA of 3.50 for all courses attended in the major at time of admission to the honors program
- Applicants to the honors program must provide as part of the completed application a written statement of purpose which explains the reasons and motivation for wanting to undertake the honors program
- Students admitted to the honors program who completes all requirements, earn an overall GPA of 3.25 and a major GPA of 3.50, presents an acceptable honors project or thesis (NSCI 493) the Vice President will direct that the student graduate with “Honors in Nanoscale Science” or “Honors in Nanoscale Engineering” and that the appropriate designation be placed on the student’s transcript.

Honors College

- Undergraduate students who are enrolled in the B.S. programs in nanoscale science or nanoscale engineering have the option and would be encouraged to participate in the UAlbany Honors College program
- Honors sections of the following CNSE courses will be offered:
  - NSCI 124H Physical Principles of Nanoscale Science and Engineering III
  - NSCI 220H Structure of Matter
  - NSCI 230H Thermodynamics and Statistical Mechanics for Nanoscale Systems
  - NENG 201H Introduction to Nanoengineering Design and Manufacturing
  - NENG 202H Introduction to Computer Programming for Engineers
  - NENG 203H Introduction to Nanoengineering Electronics

Nanotechnology Minor

- A provision has been established to provide these students the option to select and complete a minor in nanotechnology
- By allowing students opting for other majors to apply 18-24 credits of their completed NSCI coursework to the Nanotechnology Minor, this provision will enable a smoother programmatic transition as students will not be required to restart coursework for a new minor
- This is a restricted minor and students may list it on their record only with permission from the CNSE Office of Student Services
- Minor in Nanotechnology: 18-24 credits of coursework in the CNSE (at least nine credits of which must be in coursework at or above the 300-level or in courses requiring one or more prerequisites) from courses with a NSCI prefix
- This is a restricted minor and a student may list it on their record only with permission from the CNSE Office of Student Services

Conclusions

- The College of Nanoscale Science and Engineering (CNSE) at the University at Albany is in the process of implementing a one-of-a-kind undergraduate degree program in nanoscale science
- This program will leverage the unique infrastructure and non-departmental ecosystem that is characteristic of the CNSE
- A four-year, 132 credit program has been developed that will lead to an education experience which is appropriate for either immediate workforce deployment or subsequent post-graduate study