AC 2012-4122: A NEW UNDERGRADUATE MAJOR IN MICROSYSTEMS AND NANOTECHNOLOGY ENGINEERING

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Hal Evensen is a professor and Program Coordinator of engineering physics at the University of Wisconsin, Platteville, where he has taught since 1999. He received his B.S. in applied physics from Michigan Technological University, and his M.S. and Ph.D. in engineering physics from the University of Wisconsin, Madison. He has research interests in nanoscale properties of photovoltaic materials, and has played a lead role in developing a new major in microsystems and nanotechnology engineering at UW, Platteville. He was awarded the National Academic Advising Association Outstanding Faculty Advisor Award in 2010.

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Dr. Tsunghsueh Wu, University of Wisconsin, Platteville

Tsunghsueh Wu has been an Assistant Professor since 2008. His research is focused on using electrochemistry to generate nanostructures, which can be applied in sensors, solar cells, and nanoelectronics.

Dr. Yan Wu, University of Wisconsin, Platteville

Yan Wu graduated from Tsinghua University, Bejing, China, in 1996 with a bachelor's degree in precision instruments and a minor in electronics and computer yechnology. She received her M.S. degree in mechanical engineering from the University of Alabama in 1998. She received her Ph.D. in electrical engineering from the University of Illinois, Urbana-Champaign, in 2005. Her Ph.D. thesis work was in the area of micro-electro-mechanical systems (MEMS) with a focus on effect of space charges on micro-to nano-scale electrostatic actuation. Upon receiving her Ph.D., she worked as a Postdoctoral Research Associate in the Department of Mechanical Science and Engineering in the University of Illinois, Urbana-Champaign, where she collaborated with Prof. William P. King and Prof. Mark A. Shannon in multiple projects using scanning probe microscopy to study material properties. In 2009, Yan Wu joined the faculty of the Department of Chemistry and Engineering Physics at the University of Wisconsin, Platteville.

Prof. Esther N. Ofulue

A New Undergraduate Major
in Microsystems and Nanotechnology Engineering

The University of Wisconsin-Platteville was approved for a new major in Microsystems and Nanotechnology Engineering in April 2011. The first students began in Fall 2011, with the first new course offered in Spring 2012. The Major builds upon a successful multidisciplinary minor of the same name, and follows the recommendations of our industrial advisors. Its goal is to prepare engineers capable of working in a variety of fields, who will contribute to newly identified needs in public and private companies – including research and development within new and existing industries – government initiatives, and public service. The Major was developed with the efforts of faculty from several departments, plus feedback from external industrial advisors, over the course of several years. The Major has two tracks: a Bachelor of Science that aims for ABET accreditation; and a Bachelor of Arts that offers more flexibility in technical electives, including courses in Chemistry and Biology, that readily accommodates double-majors. This paper details the process by which the major was developed, and describes challenges such as faculty development and competition for scarce resources. In addition, we describe the program's curriculum, budget, educational outcomes and objectives, and plans for the future. It is hoped that this report will aid others aiming to develop similar, multidisciplinary programs.

Introduction

In April 2011, the UW System Board of Regents approved a new degree program in Microsystems and Nanotechnology Engineering at the University of Wisconsin-Platteville. This represented a bold step, through a new program that is both interdisciplinary and at the leading edge of technology. Ours is a public, undergraduate institution with 7,500 students and seven accredited engineering programs. These engineering programs – Electrical Engineering, Engineering Physics, Civil Engineering, Environmental Engineering, Software Engineering, Mechanical Engineering, and Industrial Engineering – are a major part of UW-Platteville's areas of emphasis, as defined in its mission statement. With an enrollment of over 1750 engineering students, the engineering college is one of the largest undergraduate-only engineering programs in the United States.

The engineering college has a long-standing reputation for excellent teaching, small class sizes, and extensive faculty-student contact and laboratory experiences. The vision of our College of Engineering, Mathematics, and Science is to be "recognized as a leader in undergraduate … education in engineering, mathematics and science." The College is further committed to "encourag(ing) departments to investigate opportunities for new programs which meet the needs of a changing society."

With this in mind, the fields of microsystems and nanotechnology were seen as areas with a lot a growth and interest, and certainly fields that would need educational innovation. At this point, it is worthwhile to provide some context on these fields

Microsystems and nanotechnology overview

Microsystems technology is rapidly maturing, thanks to recent standardization in design software, testing, prototyping, and packaging of MEMS (microelectromechanical systems) devices. The total worldwide market for MEMS devices was $68 billion in 2005, up from $30 billion in 2000; [i] the U.S. MEMS sensors market stood at $7 billion in 2009, with growth to $8.5B – $13B projected. [ii] The most common uses at present are in telecommunications; consumer products (inkjet printers, microphones, and accelerometers); automotive applications (accelerometers and tire pressure sensors); and medical and life science applications. [iii]

As MEMS continues to mature, new sensors and new applications will spread. In automotive electronic applications, it is projected that the market will grow as these sensors spread into automotive applications for speed, pressure, and temperature.[iv] Additionally, "smart" MEMS sensors will likely find new niches in indoor environmental controls, [v] and in biological systems as they are merged with microfluidic devices.

Microfluidic analytic devices are beginning commercial implementation for protein research and drug screening; they can also be employed as a means of delivering sub-microliter samples to electronic MEMS devices. This combination will open MEMS to uses in agriculture, such as: real-time monitoring of the health of crops and herds; early pathogen detection; and tracking and identification of agricultural products as they move from the farm to the consumer. [vi]

The nanotechnology market, while not at the level yet of MEMS, is expected to surpass it in the near future. This is reflected by the large investments by both government and industry. The U.S. Federal Government, through the National Nanotechnology Initiative,[vii] provides $2.1 billion toward nanoscale research in 2012.[viii] State governments have added hundreds of millions more,[ix] and have launched at least 25 statewide initiatives[x] in nanotechnology. Meanwhile, all Fortune 500 companies in materials, electronics, and pharmaceuticals have made investments in nanotechnology since 2002.[xi]

Nanotechnology is expected to emerge throughout the economy in improved products and new applications enabled by these improvements: the National Science Foundation has famously projected that $1 trillion in products and two million jobs worldwide will be affected by nanotechnology by 2015.[xi] Applications that are already in the marketplace include burn and wound dressings, sunscreens, longer-lasting tennis balls, stain-free clothing, and more. Anticipated applications include drug delivery, solar cells, fuel cells, and wear resistance in materials.[xii] Indeed, in the latest renewals of the National Nanotechnology Initiative, investments in Nanomanufacturing are growing relative to other efforts: the focus of funding is moving toward application development and manufacturing scale-up as research into nanotechnology produces more results.

This list of predominantly "everyday" applications illustrates the expected pervasiveness of nanotechnology. Further, it demonstrates the importance of this field to engineering, as all manufactured products involve engineering at several levels. It is imperative that our newly trained engineers become familiar with the new tools and approaches that become available through nanotechnology. Engineers must be able to understand what properties can be enhanced through nanotechnology, and subsequently, how to apply and/or analyze nanoscale treatments and nanostructures.

The need for engineers in nanotechnology has been expressed well by Neil Gordon of the Canadian NanoBusiness Alliance. In short, engineers are needed in order to serve the same roles they always have:[xiii]

- to transform science into products
- to educate and support potential customers
- to transition lab work into production
- to evaluate commercial viability
- to create new nanotech companies
- to interface between researchers and investors

By receiving training in engineering and microsystems/nanotechnology, microsystems and nanotechnology graduates will be able to play these roles in the marketplace.

Program history

With this in mind, our Dean convened an interdisciplinary group of faculty in early 2005 to determine a direction for our educational efforts in the area of microsystems and nanotechnology. This group included faculty from Chemistry, Engineering Physics, General Engineering, Electrical Engineering, and Mechanical Engineering. One of our first decisions was to work toward a program that combined both microsystems and nanotechnology. This was because that while nanotechnology has great promise for the future, it was also seen as very research-intensive and rather different from the norm at our university, where about 5% of our engineering graduates consider graduate school. The field of microsystems, on the other hand, is rapidly maturing thanks to recent standardization in design software, testing, prototyping, and packaging of devices, and has the "toolkit" of an engineering discipline. Another motivation to unite these fields was the special "small scale" techniques they require, and because of the cross-disciplinary nature that they share. This committee thus marks the start of our university's progress toward a degree program, which is delineated in the timeline of Figure 1.

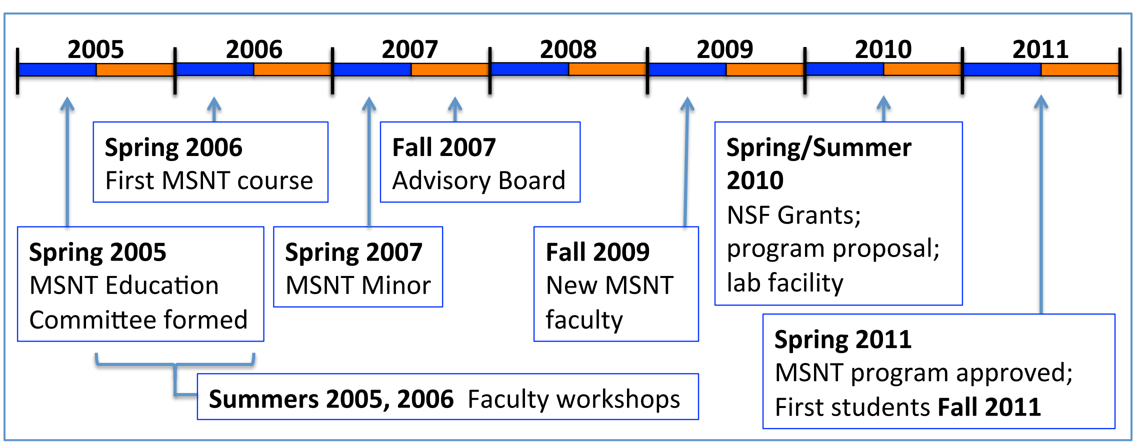

Figure 1. Timeline for the development of UW-Platteville's program in Microsystems & Nanotechnology Engineering.

At that time, our faculty had limited experience in these areas; none had received their degrees in this area, and only a few had research collaborations that involved aspects of nanotechnology. Those with experience didn't feel they had the breadth of experience needed to get the big picture for a field such as nanotechnology. Therefore, the College sent several of us to workshops with this goal in mind. These included workshops offered by the NACK Center at Penn State University, as well as ASME's Nano Training Bootcamp. These workshops had something new for everyone, and provided a chance to find how one's specialty fit within the larger discipline.

In Spring 2006, we offered our first course in microsystems and nanotechnology, as a "special topics" course. This three-credit course was open to seniors in engineering, chemistry, and biology. It was team-taught by eight instructors and topics included: (1) introduction/overview of course; (2) materials in MEMS/Nano; (3) microsystem fabrication/characterization; (4) microelectronics; (5) mechanical design and reliability; (6) quantum effects and photonics; (7) nanobiotechnology. The modules reflected the "niche" expertise of the faculty involved, and allowed them to dig into areas that they may have lacked familiarity. Faculty taught from their own notes. In addition, the course had four hands-on modules: (1) production and measurement of nanowires (adapted from the UW-Madison Materials Research Science and Engineering Center [MRSEC]'s video lab manual);[xiv] (2) operation of scanning tunneling microscope (a small educational unit from Nanoscience, Inc., previously utilized in our Modern Physics course); (3) nanopatterning, a "home-made" experiment derived from the research of the author;[xv] (4) exploring products incorporating nanotechnology, using a kit from Penn State's NACK Center.[xvi]

The course was well received by students and faculty alike. While having a large number of instructors allowed each of us to stay in our "comfort zone," course management proved to be its shortcoming. For one, students complained that different faculty frequently covered redundant topics; for another, the student workload was excessive. These were addressed in the next year's offering by reducing the number of instructors (but not the number of modules), and by using two textbooks (one for MEMS, one for nanotechnology), which greatly helped organize the structure of the course. Teaching the course stoked the enthusiasm of the instructors, indicating that the "team approach" was a good way to start this new, interdisciplinary venture. This enabled several people to make direct contributions to the new effort, and everyone greatly enjoyed the challenge and excitement of a new course. In an effort to simplify the course logistics, however, the number of instructors fell every semester; until it was taught by a single, new instructor in 2011, who had direct experience with every topic in the course (and had co-taught it the previous year).

The minor

The spring semester of 2007 marked the introduction of our new minor in Microsystems and Nanotechnology (MSNT). It was structured so that students majoring in Biology, Chemistry, Electrical Engineering, Engineering Physics, and Mechanical Engineering could complete the minor with only six credits beyond their graduation requirements – mirroring the popular mathematics minor completed by many engineering students, and reflecting the fact that these new areas build upon the traditional disciplines. The four common courses in the minor include: Microsystems and Nanotechnology (described above); Nanoscale Characterization and

Fabrication; Design and Simulation of MEMS; and a one-credit independent study research requirement (all described below). Since many biology majors did not have the math prerequisites for the MEMS course, they had the option of instead taking Physical Chemistry from the Chemistry department. We have had students from all five programs complete the minor, with the majority from Mechanical Engineering (which produces 100 graduates per year); a disproportionate share – about 40% of the minors – from Engineering Physics (about 12 graduates per year); and only one biology major (50 graduates per year). These student numbers indicate (1) the draw (or repulsion) of engineering for some students; (2) the strong draw for students already predisposed to interdisciplinary fields.

Nanoscale Characterization and Fabrication is a two-credit laboratory course. The goal is for students to learn fundamental fabrication methods in Nanoscience, as well as advanced measurement techniques such as non-contact atomic force microscopy and DNA analysis. Additionally, they learned to produce thin films, nanoparticles, and simple organic electronic devices (nanocrystalline solar cells; organic LEDs). The UW-Madison MRSEC web site was very helpful for the latter experiments.[xvii] This course was initially divided among four faculty, who were each able to focus on their strongest areas: biochemistry (Chemistry faculty), nanobiotechnology (Biology faculty), and plasmas and scanning probe microscopy (two Physics and Engineering Physics faculty). Since its initial offering, the number of instructors has been reduced to two, which greatly aided the logistics of conducting the course as well as scheduling it. For our current set of faculty, it is unlikely that this course will shrink to a single instructor, given our expertise gap between "wet" (biochemical) and "dry" experiments.

Design and Simulation of MEMS is a three-credit course that is structured to give the students the tools to design, digitally fabricate, and simulate reliable MEMS devices. The course includes an in-depth study of mechanics and microelectronics concepts and how to couple them to design functioning MEMS. Probabilistic design concepts are introduced, and students learn to understand failure modes in MEMS and how to design for reliability. Finite Element Analysis software is used to simulate and probabilistically design MEMS, and students also learn how to digitally fabricate MEMS using CAD based design layout and visualization software (SUMMiT V™, from Sandia National Laboratory). This course has always been taught by two instructors; one to address the microelectronics (slightly less than one-half of the course), and one for the MEMS simulation. As with the other courses, this team-teaching allows the instructors to remain in their comfort zones associated with their research and experience. The Mechanical Engineering and Engineering Physics programs both accept this course as a design elective.

The independent study/research course, Research in Microsystems and Nanotechnology, is a "capstone" course of sorts and was implemented as a conscious effort to require a research experience of students in the minor. This has two important aspects: (1) it presents a valuable opportunity to pursue interdisciplinary research with a faculty member; (2) much of nanotechnology is in the research phase and experience with research is thus directly relevant to students wishing to continue in this area. Students have pursued projects involving experiments and/or modeling and simulation, from MEMS to quantum systems to stem cell technology to AFM studies of ferroelectrics. The coordinating faculty member provides students a synopsis of the areas of interest for the nine participating faculty as a starting point; it is then up to the student to meet with participating faculty and select a project. We have had mechanical engineering students pursue projects with biology faculty, and biology students working with engineering faculty. At semester's end, students present their projects to all other involved students and faculty, and turn in written reports. This course has led to a large increase in the amount of student/faculty research in our College and is perhaps the students' easiest "selling point" after they graduate.

External advisory board

In October 2007, we convened our first Microsystems and Nanotechnology Advisory Board meeting, comprised of four industry representatives, one member from a national laboratory, and one from academia. The industry representatives included engineers from small and multinational companies. The Board met to review and discuss the Minor in Microsystems and Nanotechnology, and they met with students in the Minor and received a student research presentation. The Board gave the new minor their resounding support. Board members praised the minor for combining Microsystems and Nanotechnology; for the strong hands-on component; and that it built on a base of science and engineering. They were most supportive, though, of the strong interdisciplinary experiences and knowledge that the students gained. Surprisingly, the desire for multidisciplinary training dominated desires for training on any particular pieces of equipment. In fact, they pointed out only a few particular equipment needs for the program; as long as the program maintained its interdisciplinary nature, then they felt that the research interests of our faculty could drive the exact nature of the "in-depth" areas to be pursued. Finally, the Board encouraged the development of a major in MSNT.

The question of a new major, though, was not a unanimous opinion of the Board, and it sparked an interesting discussion that could apply to any new, emerging program. The university and national lab representatives strongly supported the idea of a new major, while the industry representatives expressed ambivalence. On the one hand, all of the companies were interested in our students for co-ops and internships. On the other hand, what would companies *think* if they received an application from a "nano" major? Would it mean anything to them? This concern was tempered with the knowledge that in five years, this could all change, but it was clear that a future degree program would need to work in close contact with our graduates' employers. (It should be noted that a subsequent survey conducted in 2010 revealed research university faculty that expressed similar reservations regarding students' application to graduate schools from a novel degree program.)

The Board's positive response put us more firmly on a path toward the new major, which until that time was not a sure thing due to some faculty and administration uncertainty; the external "seal of approval" was significant to ease any faculty ambivalence and administrative reticence.

Building toward a new major

The next three years were spent developing educational objectives and outcomes for the new major; setting a curriculum and implementation plan; and developing our campus' infrastructure in order to support it. This included acquiring equipment, writing proposals, and hiring a new faculty member to support this major.

It was decided that to build on UW-Platteville's success and expertise in engineering education, the degree would be a hands-on, classroom-based engineering degree that would ultimately seek accreditation (like all other engineering degrees on campus). Also, in order to appeal to the broadest range of students – especially while the degree program would be ramping up and evolving – we established two tracks: an engineering degree that would seek accreditation, and a science degree, which would not. The two paths have significant overlap (see below); the science degree essentially exchanges engineering courses for breadth in the sciences. Additionally, the science degree allows majors in several engineering and science disciplines to complete a double major in 10 semesters. The dual-track plan thus keeps the micro/nano field open to both engineers and scientists and allows us a good chance to maintain student numbers while the major undergoes changes and development as we move forward.

We prepared proposals for the National Science Foundation: one for Nanotechnology Undergraduate Education (NUE), to support our curriculum development activities, and one for Major Research Instrumentation (MRI), to pursue a high-end atomic force microscope to support student and faculty research. After rejection, these proposals were successfully resubmitted. This funding has proven to be very important to our program.

At this point, we had made enough progress that the university was willing to bring in an additional faculty member, who provided greatly needed expertise. This position was placed in the Engineering Physics department, and justified by being split with Physics; i.e., half of this person's teaching load would be introductory physics, and half would be in the new minor/major. This represented a significant boost to our efforts, and a large but necessary commitment on the university's part. Part of the appeal (to the administration) was the fact that 50% of this hire would be able to address existing needs outside of the new effort, which had relatively small student numbers compared to existing programs. This commitment has been fruitful; this person was lead co-PI on the successful grant applications to the NSF programs. The combination of expertise and demonstrated commitment by administration that this position represented were key elements to the successful proposals.

Structure of the new major

A set of educational objectives, which are goals for graduates within five years of graduation, and educational outcomes, which are goals for students completing the program, were developed. These were based on the objectives and outcomes for the existing, interdisciplinary Engineering Physics major, with added changes derived from the input of the 2007 Industrial Advisory Board. The objectives and outcomes are given below.

Educational objectives

The Microsystems and Nanotechnology program provides MSNT majors with a quality undergraduate education in liberal studies, mathematics, science, and engineering. The expectation of this program's graduates is that they will be successful high-tech engineers working in a variety of fields and contributing to newly identified needs in cutting edge public and private companies, including research and development within new and existing industries, government initiatives, and public service. Graduates are expected to have met the following educational objectives three to five years after graduation:

a. Graduates will possess a solid background in science, mathematics, and engineering fundamentals with an in-depth knowledge about microsystems and nanotechnology and its applications to a variety of disciplines.
b. Graduates will be able to solve nontraditional or multidisciplinary engineering problems that involve design, fabrication, testing and application of microsystems and nanotechnology.
c. Graduates will be employed in successful careers in the fields of engineering and/or science, or be pursuing post-graduate study in related fields.
d. Graduates will exhibit strong communication and interpersonal skills, as well as professional and ethical principles, and function effectively as members and leaders of multidisciplinary teams
e. Graduates will engage in life-long learning in order to remain technically current in their field and to know about contemporary issues in their field.

Educational Outcomes

Graduates of the Microsystems and Nanotechnology (MSNT) program must achieve the following outcomes as part of their education:

1) Microsystems and Nanotechnology graduates must have demonstrated
   a) a working knowledge of fundamental science and basic engineering principles that are the foundation of microsystems & nanotechnology
   b) the ability to identify, define and solve complex multidisciplinary problems
   c) the ability to apply the design process to engineering problems, culminating with the execution of a professional design project
   d) the ability to formulate, conduct, analyze, and interpret experiments including micro- and nano-scale phenomena and systems, using the appropriate specialized tools
   e) the ability to independently establish procedures for original research

2) Microsystems and Nanotechnology graduates must have developed professional skills which will allow them to
   a) communicate their ideas effectively, both orally and in writing,
   b) function effectively in multidisciplinary and diverse, global teams.
   c) use appropriate engineering and scientific techniques and tools.

3) Microsystems and Nanotechnology graduates must have the educational background to be good citizens as well as good engineers, including
   a) an understanding of their professional and ethical responsibility to society
   b) knowledge of the relationship between technology and society,
   c) a desire for life-long learning to improve themselves as citizens and engineers,
   d) and a knowledge of technical contemporary issues.

Curriculum

The degree program has two paths to graduation: a Bachelor of Science and a Bachelor of Arts. The B.S. will seek accreditation as an engineering degree (ABET/Engineering Science). The B.A. will also have engineering content, but not enough for ABET accreditation: it essentially exchanges engineering requirements for science requirements compared to the B.S., and will therefore be more accessible to traditional science students.[xviii] (Like all other programs on campus, however, the B.A. will seek accreditation by the Higher Learning Commission.) Thus, the B.A. will be viable as a *second* degree for students majoring in engineering, chemistry, or biology, while the B.S. will offer a faster path toward graduation with a new – but accredited – engineering degree. We thus address employers' unfamiliarity with this new degree program, especially in the early years of the MSNT program, one of two ways: (1) with an accredited engineering degree; or (2) as an addition to an already-accepted degree program. It should be noted that the B.A. is also a stand-alone degree; however, at this time we are advising students away from the "B.A.-only" option until we can more clearly determine a successful path to employment or graduate school. We are currently working with employers and other universities to establish these links.

We expect the student enrollment of the degree in Microsystems and Nanotechnology to run along a similar pattern as other interdisciplinary degrees at our university, notably Engineering Physics (EP). A large number of EP students initially pursued double majors, as the labor market was still unused to the newly minted discipline; as the degree became established and more familiar, however, the number of double-majors dropped and over 95% of EP students now pursue a single major. The program planners anticipate that many of the students initially enrolling in the MSNT program will choose to enroll as B.A. double-majors. Faculty and advisors will actually encourage double majoring for students with less-clear career goals or students seeking a broader foundation. As the degree becomes more familiar, the B.S. enrollment will grow. (Further, as the accreditation process develops for this new field, it may well turn out that the B.A. degree could also seek ABET accreditation in the future.)

The MSNT program will teach students the fundamentals of science and engineering, and then how to creatively apply these theories to new problems. **Table 1** presents the proposed list of requirements. The "notes" column marks new courses (N), modified replacements of courses offered by the sponsoring programs (R), and existing courses offered outside and within the sponsoring departments (O). All students will complete a capstone project in MN 4930, Senior Design. The credit load is consistent with existing campus engineering programs.

Table 1. Proposed Microsystems and Nanotechnology Engineering B.S. Degree

Area	Notes	Credits	Total
General Studies Core			**31**
English 1130, 1230	O	6	
Humanities and Social Sciences electives	O	21	
Speech	O	2	
Physical Education and Wellness	O	2	

Math and Science			**44**
Math 2640, 2740, 2840 (Calculus I, II, and III)	O	12	
Math 3630 (Differential Equations)	O	3	
Physics 2240, 2340 (General Physics I & II)	O	8	
Physics 3140 (Modern Physics)	O	4	
Chemistry 1450 (Chemistry for Engineers)	O	5	
Chemistry 3540 (Organic Chemistry)	O	4	
Chemistry 4630 (Biochemistry)	O	4	
Biology 2040 (Cell Biology)	O	4	
Engineering			**32**
GE 1000 (Engineering Success Skills)	O	1	
GE 1030 (Introduction to Engineering Projects)	O	1	
GE 2030 (Engineering Modeling and Design)	O	3	
GE 2130 (Engineering Mechanics – Statics)	O	3	
GE 2230 (Engineering Mechanics – Dynamics)	O	3	
GE 2340 (Mechanics of Materials)	O	4	
GE 2630 (Basic Thermoscience for Engineers)	O	3	
EE 1210 & 2210 (Circuit Modeling II)	O	7	
EE 3130 (Solid State Electronic Devices)	O	4	
ME 3030 (Dynamical Systems) [student may use EE 2220]	O	3	
Microsystems and Nanotechnology			**19**
MN 1010 (Introduction to Microsystems and Nanotechnology)	N	1	
MN 3020 (Nanoscience and Nanotechnology)	R	2	
MN 4020 (Nanoscale Characterization and Fabrication)	O	2	
MN 3130 (Microfabrication)	R	3	
MN 4230 (Design & Simulation of MEMS)	O	3	
MN 4330 (Microfluidics)	N	3	
MN 3990 (Research & Seminar)	N	2	
MN 4930 (Senior Design)	N	3	
Engineering Electives			**6**
EE 3020 (Analog Electronics)	O	4	
EE 3310 (Automatic Controls)	O	3	
EE 4050 (Adv. Analog Electronic Circuits)	O	4	
EE 4310 (Modern Controls Systems)	O	4	
EP 3640/EE 3140 (Electric & Magnetic Fields)	O	4	
EP 3240 (Applied Mechanics)	O	4	
EP 4140 (Applied Optics)	O	4	
EP 4210 (Sensors Laboratory)	O	2	
EP 4220 (Applications of Quantum Mechanics)	O	2	
ME 3040 (Engineering Materials)	O	3	
ME 3230 (Manufacturing Processes)	O	3	
ME 3330 (Design of Machine Elements)	O	3	
ME 4330 (Automatic Controls)	O	3	
ME 4430 (Advanced Materials)	O	3	
ME 4440 (Failure of Materials)	O	3	
ME 4500 (Biomedical Engineering)	O	3	
ME 4800 (Finite Element Method)	O	3	
ME 4840 (Vibration System Design)	O	3	
ME 4830 (Mechatronics)	O	3	
MN 4990 (Indep. Study in Microsystems & Nanotech.)	R	1	

Other requirements [also counts as Humanities elective]			**(3)**
Philosophy 2540 (Science, Technology, and Ethics)	O	3	
Total minimum to satisfy MSNT major			**132**

Most of the courses are currently being offered in a spring/fall rotation. Of the 19 credits to be offered in the MSNT core (11 credits Spring, 8 credits Fall), 14 credits will be new MSNT courses. (Five of these new credits will result from expanding an existing three-credit course.)

- MN 1010, Introduction to Microsystems and Nanotechnology (1 credit; 2 lab hours weekly): An overview of MEMS, microfluidics, and nanotechnology and their applications in engineering and their impact on society. Course will include hands-on projects in micro- and nano-scale fabrication, and is intended as a means for first year students in the major to gain knowledge in their area. *(Spring)*
- MN 3020, Nanoscience and Nanotechnology (2 credits; 2 lecture hours and one lab/discussion hour weekly): An introduction to the sub-100 nanometer scale aspects of chemistry, physics, and biology, and how these aspects can be combined to provide solutions to engineering problems. Topics include fabrication and measurement/ analysis techniques, including hands-on modules and experiments, and recent applications will be presented as case studies, including sensors, biology & medicine, electronics, and new materials. Course also includes social, legal, and ethical aspects of applied nanoscience. Prerequisites will include Physics II, Chemistry, and MN 1010. This course will be adapted from the existing, 3-credit introductory course, which will be phased out. *(Spring)*
- MN 3130, Microfabrication (3 credits; 3 lecture hours and one lab/discussion hour weekly): An overview of the basic science and engineering of microelectronics and microelectromechanical systems (MEMS) is presented: fundamental concepts of semiconductors and mechanics; microfabrication processes and surface micromachining; electrostatic sensing and actuation. CAD-based MEMS design and visualization software is taught and used for student group design projects. Associated characterization tools will also be introduced, as well as how these are integrated to produce a microdevice. This course will incorporate hands-on laboratory modules in fabrication and characterization techniques. Prerequisites will include Physics II, Chemistry, and MN 1010. To be adapted from the existing, 3-credit introductory course, which will be phased out. *(Spring)*
- MN 3990, Research & Seminar (2 credits; 1 lecture and 3 laboratory hours weekly): This course illustrates the process of research in the interdisciplinary fields of Microsystems and Nanotechnology. Students will learn to design, execute, analyze, and present research. Through laboratory exercises and projects, augmented by a combination of literature readings and discussions, students will experience the challenges and rewards of acquiring scientific information. Prerequisites/Corequisites will include English, Modern Physics, Cell Biology, and Organic Chemistry. *(Spring)*
- MN 4020, Nanoscale Characterization and Fabrication (2 credits; 1 lecture and 3 laboratory hours weekly) is the existing Nanofabrication course. Prerequisites will include MN 3020. *(Fall)*

- MN 4230, Design & Simulation of MEMS (3 credits; 3 lecture hours and one lab/discussion hour weekly) is the existing MEMS Simulation & Design course. Prerequisites will include MN 3130 and Mechanics of Materials. *(Fall)*
- MN 4330, Microfluidics (3 credits; 3 lecture hours and one lab/discussion hour weekly): An introduction to the properties of fluids (and biological fluids) in microchannels, and the features of microfluidic devices and Lab-On-A-Chip. Includes a review of fabrication techniques, microfluidic chemical analytical systems, and soft lithography. This course focuses on those aspects of microfabrication that are best suited to micropatterning of surfaces and microfluidic chemical analytical systems. This course will incorporate hands-on laboratory modules in fabrication and characterization techniques. Prerequisites will include MN 3130 and an advanced Biology or Chemistry course. *(Fall)*
- MN 4930, Senior Design (3 credits): Integration of technical knowledge in an open-ended, industry-sponsored comprehensive design project that simulates an engineering project environment, including teamwork, project management, and oral and written reports. Prerequisites will include MN 3130, MN 4020, and within one year of graduation. *(Spring)*
- MN 4990, Independent Study in Microsystems & Nanotechnology (1-3 credits): Study of special topics and/or developments of special projects having department approval. Prerequisite: permission of instructor.

The Bachelor of Arts degree in Microsystems and Nanotechnology will be more oriented to the sciences rather than engineering. The B.S. degree has 51 credits of engineering, 35 credits of science, and 15 credits of math (accreditation requires 48 engineering credits and 32 math/science credits). The B.A. degree requires 28 credits of engineering, 37 credits of science, 11 credits of math, and 25 technical elective credits from science and/or engineering. The flexibility to select a technical emphasis precludes engineering accreditation for the B.A. degree.

With the guidance of their faculty academic advisor, students select one or two emphases within the major, from Biology, Chemistry, Electrical Engineering, Engineering Physics, Mechanical Engineering, and Microsystems/Nanotechnology Engineering (25 credits total), depending on their career plans. The required courses that differ from the B.S. requirements are shown in Table 2.

Table 2. Proposed Microsystems and Nanotechnology Engineering Degree (B.A.). Only differences with the B.S. degree are shown.

Area	Notes	Credits	Total
Math and Science – Required (only additions or changes from B.S.)			**41-44**
Math 2640, 2740 (Calculus I, II; no Calculus III or Differential Equations)	O	8	
Math 4030 (Statistical Methods with Applications) *or* Math 1830 (Elementary Statistics)	O	3	
Physics 3140 (Modern Physics) **or** Chemistry 4130+ 4140 (Physical Chemistry + Lab)	O	4	
Chemistry 1450 (Chemistry for Engineers) **or**	O	5 **or** 8	

Chemistry 1140+1240 (General Chemistry I & II)			
Chemistry 3510 (Organic Chemistry Lab)	O	1	
Engineering – Required courses only			**5-9**
GE 1000 (Engineering Success Skills)	O	1	
GE 1030 (Introduction to Engineering Projects)	O	1	
EE 1210 & 2210 **or** GE 2930 (Circuit Modeling I & II **or** Applications of Elect. Eng.)	O	7 **or** 3	
Microsystems and Nanotechnology – Required			**16**
All B.S. MSNT courses except MN 4230 (Design & Simulation of MEMS) are required.			
Engineering Science Electives (select 10-12 credits)			**10-12**
GE 2130 (Engineering Mechanics – Statics)	O	3	
GE 2340 (Mechanics of Materials)	O	4	
GE 2630 (Basic Thermoscience for Engineers)	O	3	
CS 1430 (C++ Programming)	O	3	
GE 2030 (Engineering Graphics)	O	3	
GE 2820 (Engineering Economy)	O	2	
Technical Electives (25 cr) ***at least 10 credits from each of one or two emphases*** **– only additions or changes from B.S. are shown**			**2**
Electrical			
EE 2220 (Signals & Systems)	O	4	
EE 3130 (Solid State Electronic Devices)	O	4	
EE3140 (Electric and Magnetic Fields)	O	4	
EE 3770 (Logic and Digital Design)	O	4	
EE 3780 (Introduction to Microprocessors)	O	4	
EP 3640/EE 3140 (Electric & Magnetic Fields)	O	4	
Mechanical			
ME 3030 (Dynamical Systems)	O	3	
ME 3640 (Heat Transfer)	O	3	
ME 4530 (Computational Fluid Dynamics)	O	3	
ME 4550 (Heat Transfer Applications)	O	3	
ME 4830 (Mechatronics	O	3	
ME 4840 (Vibration System Design)	O	3	
ME 4850 (Computer Aided Engineering)	O	3	
Engineering Physics			
EP 3240 (Applied Mechanics)	O	4	
EP 4010 (Engineering Physics Laboratory)	O	2	
EP 3640/EE3140 (Electric and Magnetic Fields)	O	4	
Chemistry			
Chemistry 2150 (Quantitative Analysis)	O	4	
Chemistry 2730 (Inorganic Chemistry)	O	4	
Chemistry 3630 & 3610 (Organic Chemistry II + Lab)	O	4	
Chemistry 4240 (Instrumental Analysis)	O	4	

Chemistry 4630+4610 (Biochemistry+Lab)	O	4	
Biology			
Biology 3240 (Microbiology)	O	4	
Biology 3330 (Genetics)	O	4	
Biology 3450 (Ecology and Evolution)	O	3	
Biology 3530 (Biotechnology)	O	3	
Biology 3620 (Immunology)	O	2	
Biology 4040 (Molecular Biology)	O	5	
Microsystems & Nanotechnology			
MN 4990 (Indep. Study in Microsystems & Nanotech.)	R	1	
MN 4230 (Design & Simulation of MEMS)	O	3	
Total minimum to satisfy MSNT Bachelor of Arts			**128**

This degree builds entirely on existing courses and does not require the addition of new sections or courses beyond those to be developed for the B.S. degree.

Comparable programs at other institutions

Only a small number of other programs exist in this area. Two similar engineering degrees that integrate nano- and microsystems include Louisiana Tech's Nanosystems Engineering, which is the first such program to be accredited by ABET (August 2011), and the University of California San Diego's Nanoengineering, begun in Fall 2010. The structure of these two programs is similar to ours: core courses in science and math and introductory engineering, an engineering specialty, and specialized courses in micro/nano. Most of the Louisiana Tech program's tracked graduates (14 of 17 since 2007) have gone on to graduate school. Other noteworthy programs include the Nanotechnology Engineering program at the University of Waterloo (Fall 2005), and Nanoscale Engineering at the University of Albany (Fall 2009). Both have created programs that have been built from the ground up, with introductory science and engineering courses replaced with courses specifically designed for the programs.

Budget and growth path

The program will add one or two courses per year, beginning with the new one-credit freshman course (MN 1010) in Spring 2012. A new faculty member is scheduled for the 2013-2014 academic year, and the current thought is that this 1.0 FTE would actually be two people each with joint appointments. This could be realized as one in Chemistry/MSNT, who would add expertise in microfluidic systems and another in engineering/MSNT [i.e. General Engineering or Mechanical Engineering or Electrical Engineering] who would add expertise in MEMS. This "split appointment" mirrors the existing MSNT faculty, who is effectively "shared" with Physics. Similarly, they would contribute to teaching introductory courses on one hand, and to developing the MSNT program and curriculum on the other.

The existing costs of the Minor, including $30k annually for supplies and equipment and the prorated existing faculty member, are $90k per year. The needs of the major are projected to add roughly $250k per year, which includes the new faculty discussed above, plus additional staff support for the suite of equipment and administrative support for the new program. The projected equipment budget will be used to build up laboratory stations for students in the major. A significant challenge for the MSNT program will be the need for equipment that is beyond the reach of a typical annual budget; the table below shows anticipated needs, with costs. Acquiring these will depend on our ability to secure external funding.

Table 3. Anticipated Equipment Needs (External Funding)

Equipment	Justification	Cost (est.); source of funding	Target acquisition
Mask Aligner (used)	To create multi-layer devices and teach lithography/etching.	$35,000; NSF (MRI, CCLI)	By 3rd year of program (2013-2014)
Optical Profilometer	3D surface profiling to measure film thicknesses, micro-devices.	$73,000; NSF (MRI, CCLI)	By 3rd year of program (2013-2014)
"Student" AFM	Growing educational needs; 'basic' characterization tool	$50,000; NSF (MRI, CCLI).	By 3rd year of program (2013-2014)
Modern Environmental SEM	Ease of use and maintenance; capable of measurements without sputter coating. Will replace aging equipment.	$750,000; NSF Major Research Instrumentation; W. M. Keck Foundation	By 2018 ABET accreditation visit

Recent activity

In early 2010 we distributed a near-final draft of the degree program proposal to several representatives from industry, academia, and federal labs. They provided constructive feedback and encouragement to proceed with this program. The most significant new point was a realization that we will need to cultivate relations with both industry *and* academia, to ensure that both will accept students from this novel major.

Based on recent and past input from our industrial constituents, therefore, we believe that there is a special need for and interest in our proposed program among industrial employers in Wisconsin and the surrounding region. The new program was approved in April 2011, and despite missing the recruiting season for students who started in fall 2011, students are already beginning to enroll in the major.

Future feedback and challenges

As of this writing, we are planning another on-campus advisory board meeting in April 2012, to review the degree program, its curriculum, and its objectives and outcomes. This group will represent a wider swath of industry than our previous meeting, including major employers of our university's current engineering graduates. The impetus is twofold. For one, now that the major is a reality, we can speak in concrete terms with the board and can begin to develop the crucial internship and co-op opportunities for students in this major. Another drive is related to the fact that we have a new chancellor, provost, and dean from when the program was proposed to the state, and all began their positions facing large budget cuts. Therefore, our program once again needs to make a clear, strong case in order to ensure that it can stay on its path for growth (which may well ultimately come at the expense of other programs on campus).

One issue was revealed during our new Dean's visits to our college's major employers and industrial donors. These contacts expressed a desire that the new major have a greater focus on materials science and engineering, which would help not only to meet their needs but also to overcome the barrier of name recognition that any new program in "microsystems and nanotechnology" will face. Thus, the details of the degree program are currently in flux as we continue to determine up the best way to meet the needs of our constituencies.

Beyond the mundane budgetary challenges, the next largest challenge to this major is staffing. While using faculty from several disciplines has been important to guide and develop the courses and program, a resulting weakness is that as of this writing all but one of the participating faculty members have their primary allegiance to another program. Only the newest MSNT faculty member thus feels direct, personal responsibility for the success of the program. This weakness has another facet, too: our committee has lost junior faculty whose home departments questioned whether they should be spending time and effort on this program instead of their own programs. We are therefore exploring a means of creating "90%/10%" (or similar) joint appointments for existing faculty, which helps to ensure participation at a contractual level and somewhat insulates the participating faculty member from the ire of their home department. The other staffing challenge is that responsibility for the new course development will fall disproportionately on only one or two people – who are already being tugged at by multiple responsibilities associated with the new major. While the new 1.0 FTE would be very useful now (not 2013-2014) to help develop courses in microfluidics and microsystems, for example, this position will have to wait until student enrollments and/or external support can justify it.

Finally, the challenges of staffing team-taught courses will need to be addressed. Team-teaching has been helpful by lowering the barrier to faculty teaching a new course; it has also been necessary as we train students who will graduate with a broad skill set not matched by any of our faculty! However, this poses difficulties in scheduling (requiring coordination with multiple departments) and staffing loads (i.e. how does the engineering college 'reimburse' the life sciences college for the contribution of a biology professor?). The nature of this degree program also poses challenges as we develop the curriculum: there are no national standards to guide us, and there are few experts with all of the skills we are trying to develop in our students.

Another challenge will be establishing strong ties with our students' potential employers and graduate programs. Faculty will need to make companies and universities aware of the skill set of our graduates, who will have an uncommon degree name on their diploma. This will be greatly aided by securing opportunities for our students in co-ops, internships, and companysponsored projects (such as Senior Design); as we have learned in Engineering Physics, the success of these students breeds more opportunities for those who follow.

The formidable challenges presented by this new program are actually common to any new program in an interdisciplinary field, and it is hoped that the lessons learned here would have application to future efforts in engineering education, which will also likely be interdisciplinary. Like our MSNT program, any new interdisciplinary engineering program will need to find a balance between the need to convey a useful skill set to students, and the need to teach them to "learn how to learn." It is hoped that the process of finding this balance in the MSNT program can be a model for other programs. Indeed, we have had several fruitful exchanges with faculty on our campus that are developing a program in Sustainable and Renewable Energy Systems; we find that faculty in this program are already using our experiences as a guide.

References

[i] R. Allan, "The MEMS market," Electronic Design, http://www.elecdesign.com, October 28 2004.

[ii] "MEMS Market Tracker," J. Bouchard et al., www.isuppli.com/Abstract/P10187_20080818095042.pdf, 2008 (downloaded 10/2009); also Yole Développment SARL (2009).

[iii] "Status of the MEMS Industry – 2009," Yole Développement, 10/2009. (www.yole.fr/pagesAn/products/mis.asp)

[iv] The National Highway Traffic Safety Administration, as required by the 2000 congressional act named the Transportation Recall Enhancement, Accountability, and Documentation Act (TREAD), has issued a rule that new vehicles weighing less than 10,000 pounds be equipped with tire-pressure warning systems. This law could create a new market for up to 70 million MEMS devices per year.

[v] New standards are being created for indoor building environments in order to take advantage of advanced sensor technology for energy savings; however, commercial sensors to meet these needs do not yet exist.

[vi] Johnson Rutzke, C., ed., "Nanoscale science and engineering for agriculture and food systems," report submitted to the United States Department of Agriculture, Cooperative State Research, Education and Extension Service, September 2003.

[vii] Announced January 2000, the NNI is the first and largest program in the world. It has led to an eightfold increase in government-funded nanotechnology research and development over the past seven years.

[viii] National Nanotechnology Initiative website, downloaded Jan. 12, 2012; (www.nano.gov/about-nni/what/funding)

[ix] S. Tibken, "Chip Makers Commit $4.4B To Semiconductor Research In NY," The Wall Street Journal, 9/27/2011.

[x] R. Gavin, "Nanotech being seen as next big thing: States, colleges jockey for research dollars," The Boston Globe, March 8, 2004.

[xi] M. C. Roco, "The new engineering world," Mechanical Engineering, vol. 2 no.1, April 2005: http://www.memagazine.org/nanoapr05/index.html .

[xii] U.S. Government's National Nanotechnology Initiative web site, http://www.nano.gov. Also see the Project on Emerging Nanotechnologies, http://www.nanotechproject.org/inventories/consumer/ (downloaded Jan. 12, 2012).

[xiii] Neil Gordon, "The Need for an Engineering Undergraduate Degree Program in Nanotechnology," presented at the University of Waterloo, May 21, 2003.

[xiv] University of Wisconsin-Madison Materials Research Science and Engineering Center, http://mrsec.wisc.edu/Edetc/index.php; video lab manuals at: http://mrsec.wisc.edu/Edetc/nanolab/index.html . Downloaded Jan. 12, 2012.

[xv] *Introduction of Hands-On Nanotechnology Modules into Introductory Engineering*, H. T. Evensen and J. P. Hamilton, Presented at the 2006 American Society for Engineering Education annual meeting, June 2006, Chicago.

[xvi] Nanotechnology Applications and Career Knowledge (NACK) Center; http://www.nano4me.org/nack.html. Downloaded Jan. 12, 2012.

[xvii] University of Wisconsin-Madison Materials Research Science and Engineering Center, http://mrsec.wisc.edu/Edetc/index.php .

[xviii] Harvard University's Engineering Science degree has similar tracks; http://www.seas.harvard.edu/teaching-learning/undergraduate/engineering-sciences, Jan. 12, 2012.