Building Leadership for the Nanotechnology Workforce of Tomorrow:

The Nanotechnology Ph.D. Program at the University of Washington

Marjorie Olmstead
Professor of Physics
Director, UW Nanotechnology Ph.D. Program

olmstd@u.washington.edu
http://www.nano.washington.edu

Does Tomorrow Need a NT Workforce?

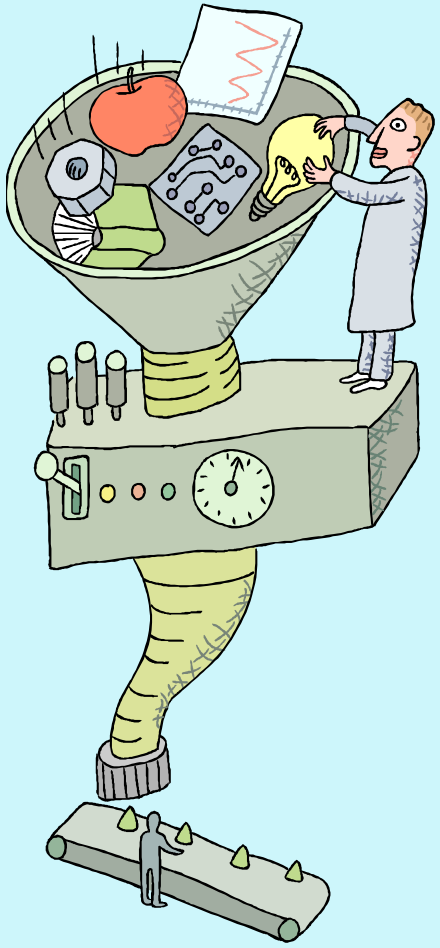
"The questions around nano are no longer whether it's coming or if it's real but just how big it will be. … the questions that are echoing from laboratories in Tokyo to the hectic offices of short-sellers on Wall Street are about money.

Activity on the ground is feverish. Some 1,200 nano startups have emerged around the world, half of them in the U.S….

February 14, 2005

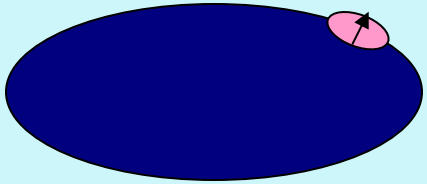
Nanotechnology Education

- Can a “standard” Ph.D. program train nanotechnologists?
- What needs to be added?
- What can be skipped?

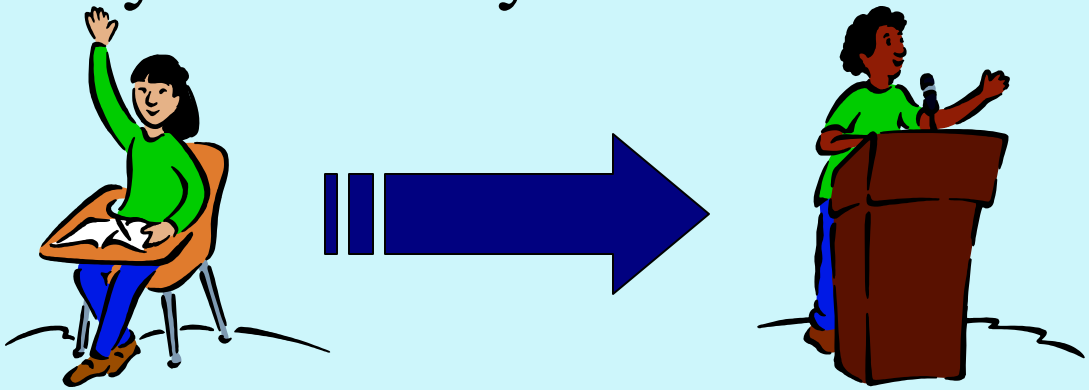


Essence of a Ph.D.

- Learn by doing how to expand Knowledge from [frontier - ε] to [frontier + ε]



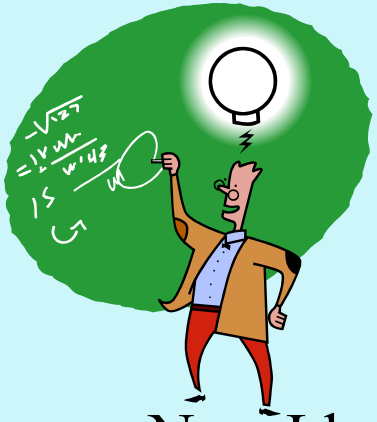
- Start out ignorant of a part of the universe, and four years later you are the world expert.



If you've done it once, you can do it again!

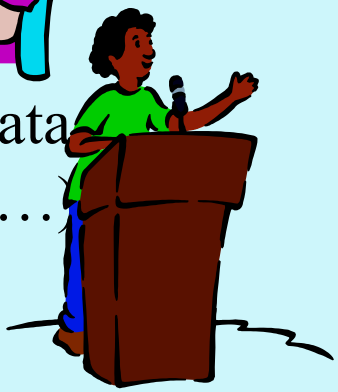
“Standard” Ph.D. Process

Take classes



Dream New Ideas

Analyze Data
(and email…)

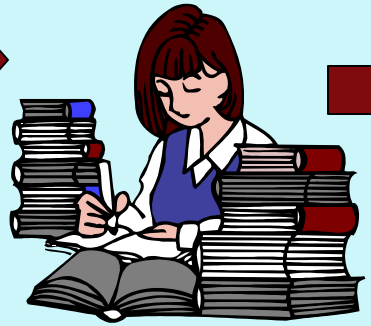


Present work

Publish results

GRADUATE

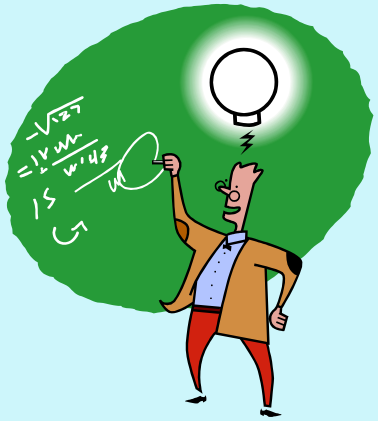
Take Data

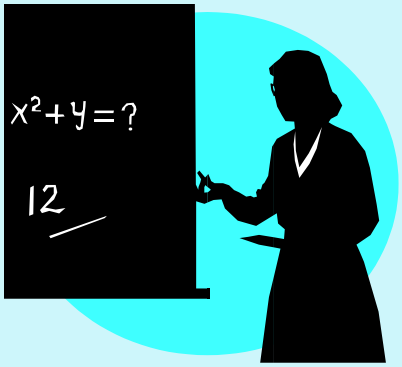


Read other
people’s ideas

“Standard” Ph.D. › “Standard Job”

- Basic Research
- Perhaps Teaching
  (though often not part of training)
- Everything else gets learned on the job

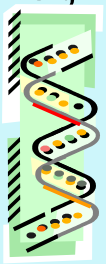


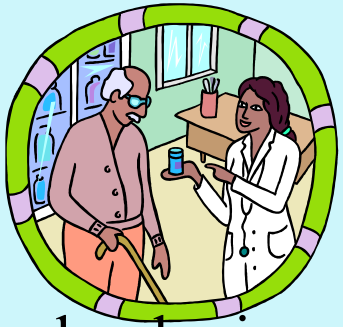


What do Nanotechnologists Do?

- All the above, PLUS:

Interact across disciplines





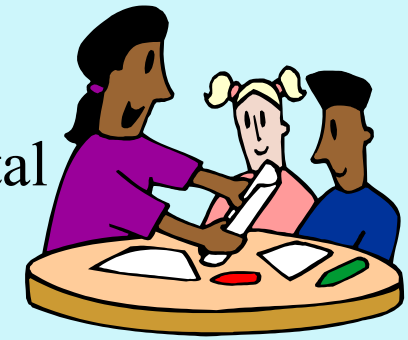
Build life-changing technologies from individual molecules

Inform public policy

Build new tools

Interact Globally

Raise Venture Capital



Teach the public

Challenges in Nanotechnology Education

- Combine Depth and Breadth of Knowledge
- Tailor Education to Individual Career Goals
- Novel Techniques using Expensive Equipment
- Prepare for Leadership in Multiple Venues
- New Field for Advisors, Students and the Public

Diversify the Ph.D. Program

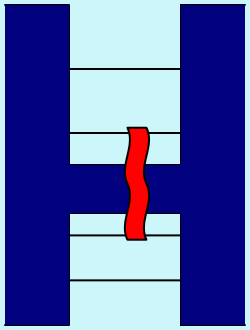
- **Discipline**
- **Venue**
- **Culture**

Diversity in Discipline

How will our graduates collaborate?

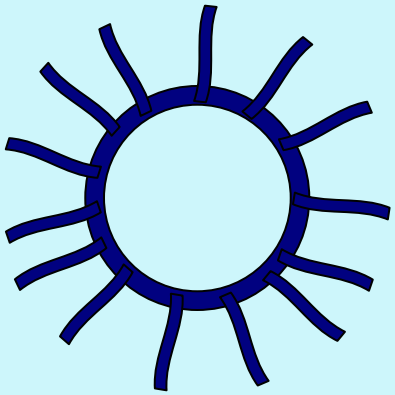
- Example Project:
  - Quantum Dot Markers for Disease Diagnosis

Physics



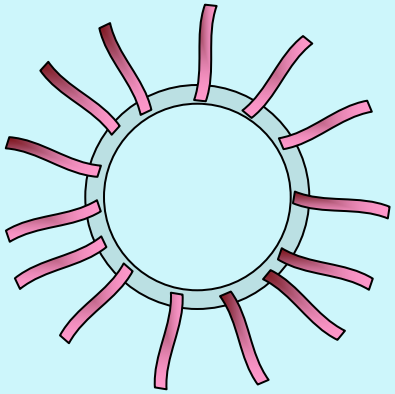
Semiconductor Quantum Wells

Chemistry



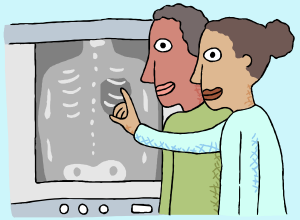
Capped Quantum Dots

Chemical and Bioengineering



Functionalized Capping Ligands

Radiology



Clinical Practice

Diversity in Venue:

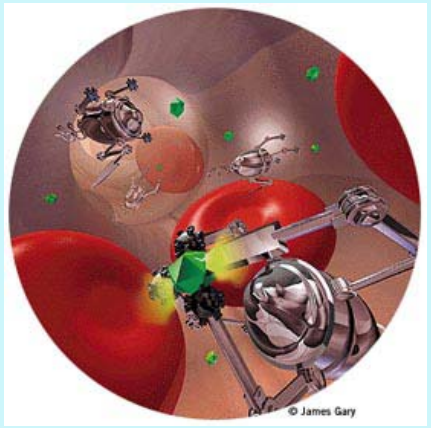
Where will our students be in 10 years?

- Academia
  - Research Universities, Small Colleges, …
- Established Industries
  - Research, Development, Fab-line Supervisors, …
- Entrepreneurial Enterprises
  - Dreaming up new ideas, Running a company, …
- National Laboratories and Non-Profits
  - Directed Team Research, User Facility Support, …
- Public Service
  - Congressional support staff, K-12 outreach …

Diversity in Culture

How will our graduates interact?

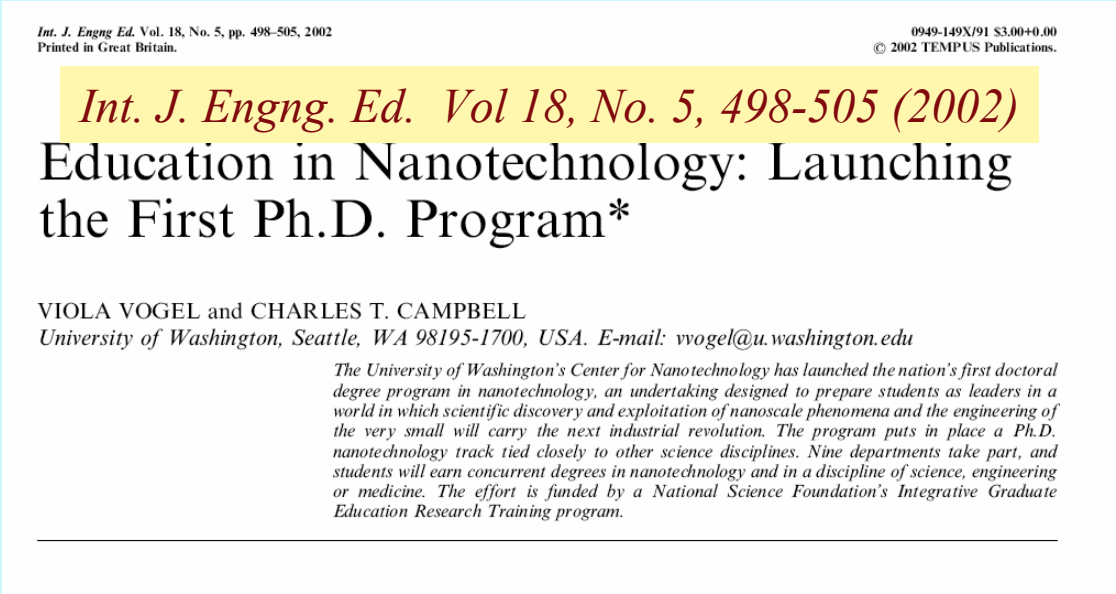
- Global Enterprise
- Ethical Considerations Essential
- Outreach to Public



Nanotechnologists should reflect and respect the cultural richness of the public they serve

UW Dual Degree Program

- Ph.D. granted in
  "Home Department" AND Nanotechnology
- DEPTH in a single discipline
  - Meet all traditional requirements in home department
- BREADTH across disciplines
  - Meet additional requirements to broaden knowledge and understanding



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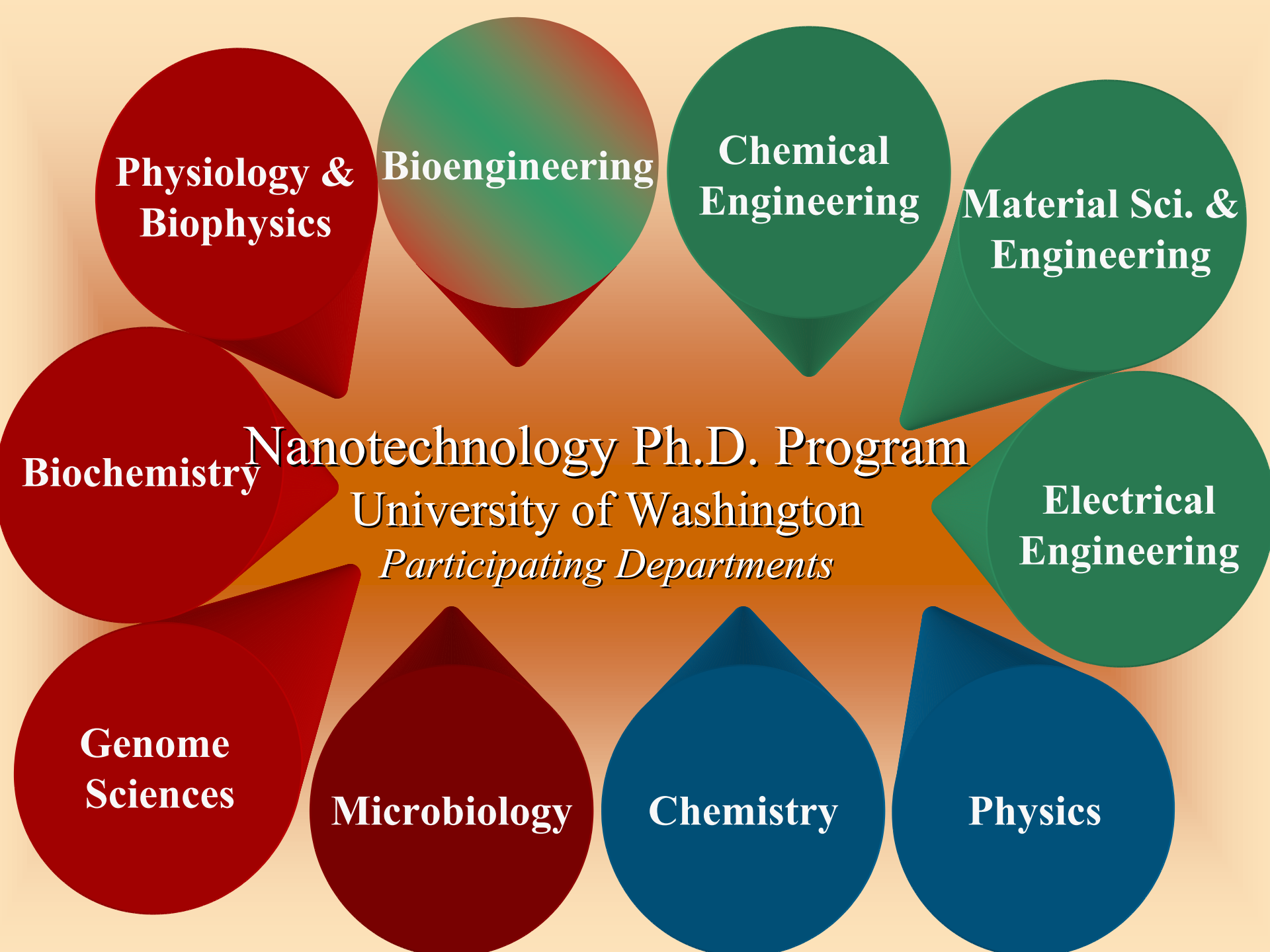
Education in Nanotechnology: Launching the First Ph.D. Program*

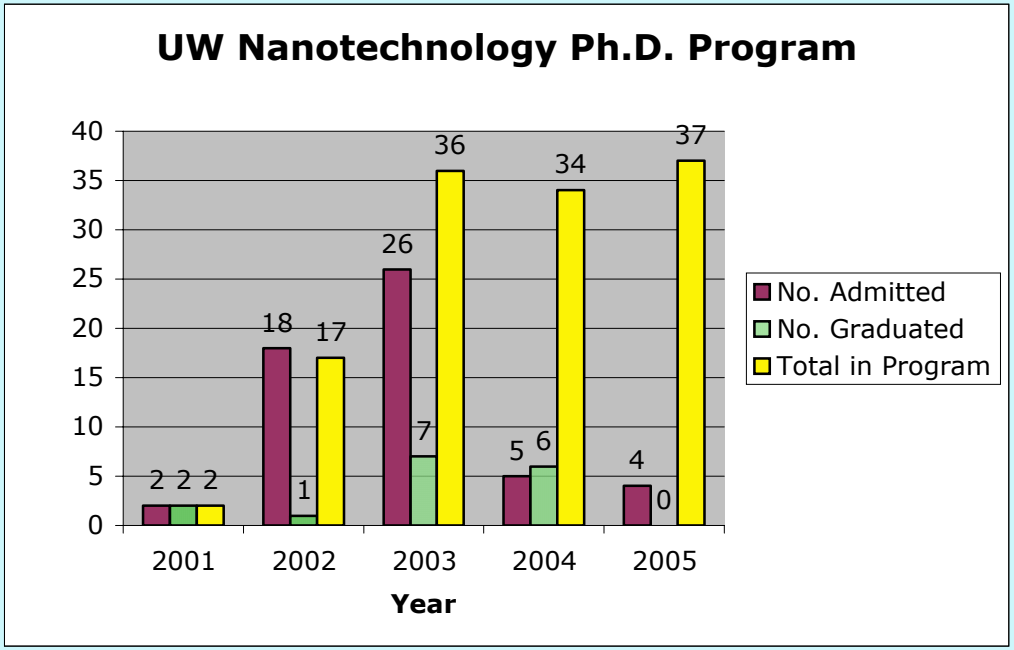
VIOLA VOGEL and CHARLES T. CAMPBELL
University of Washington, Seattle, WA 98195-1700, USA. E-mail: vvogel@u.washington.edu

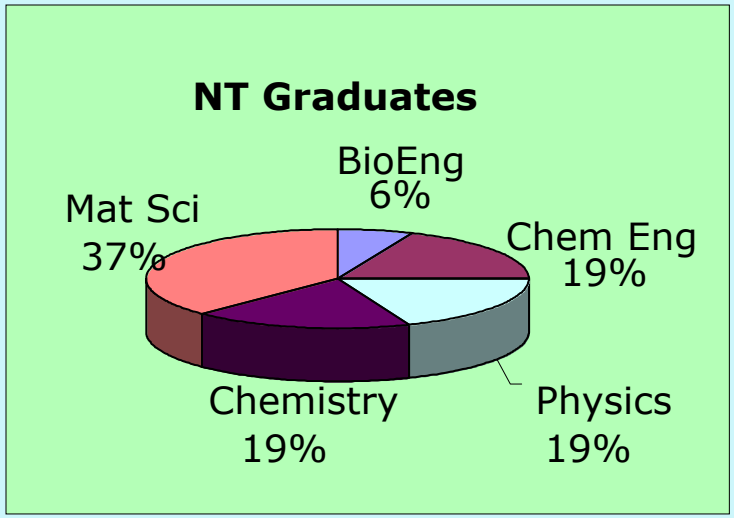
The University of Washington's Center for Nanotechnology has launched the nation's first doctoral degree program in nanotechnology, an undertaking designed to prepare students as leaders in a world in which scientific discovery and exploitation of nanoscale phenomena and the engineering of the very small will carry the next industrial revolution. The program puts in place a Ph.D. nanotechnology track tied closely to other science disciplines. Nine departments take part, and students will earn concurrent degrees in nanotechnology and in a discipline of science, engineering or medicine. The effort is funded by a National Science Foundation's Integrative Graduate Education Research Training program.

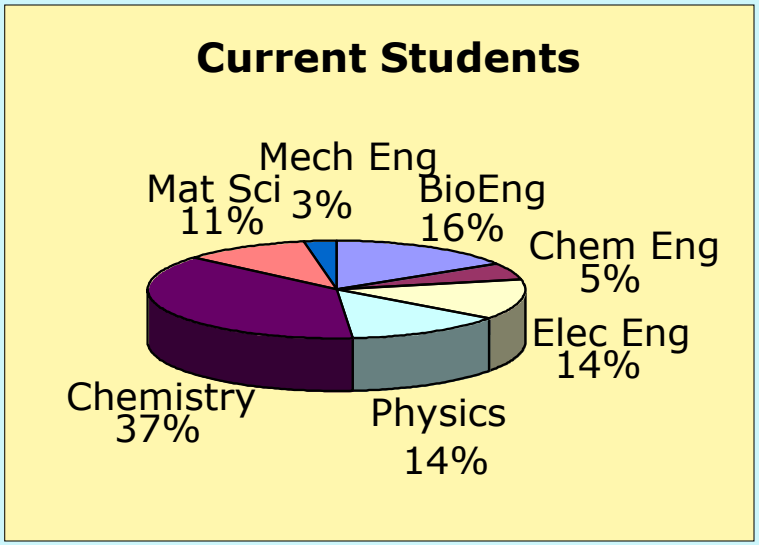

Physiology & Biophysics
Bioengineering
Chemical Engineering
Material Sci. & Engineering
Biochemistry
Nanotechnology Ph.D. Program
University of Washington
Participating Departments
Electrical Engineering
Genome Sciences
Microbiology
Chemistry
Physics

Program History

- Started in 2001
- 16 Graduates to Date
- 37 Current Students
- 75 Faculty
- 10 Departments
- 3 Colleges







Dual Degree in Nanotechnology

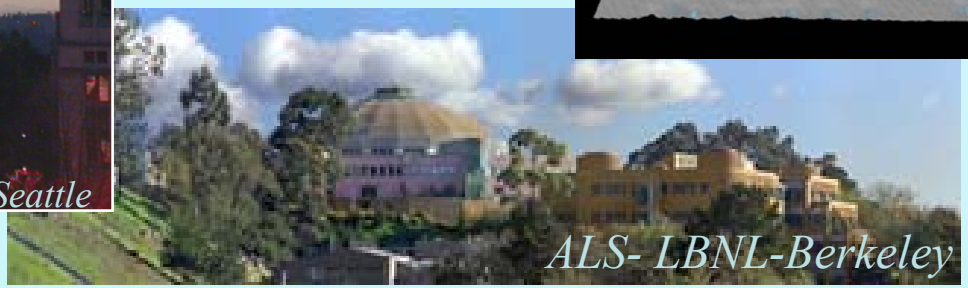
1. Thesis in Nanoscale Science or Technology
   - Approved in quality by home department
   - Approved as "nano-relevant" by NT Standards Committee
   - Advisor + at least one other committee member in the Center for Nanotechnology
2. Core course *Frontiers of Nanotechnology*
   - Student joint projects across disciplines
   - Discuss societal impact as well as science & technology
3. Research Rotation
   - ≥ 1 quarter research *outside* advisor's home department
4. Nano-relevant Course Work
   - ≥ 3 courses, ≥ 2 of which are *outside* home department
5. Nanotechnology Seminar
   - Attend ≥ 80% of seminars, ≥ 4 quarters

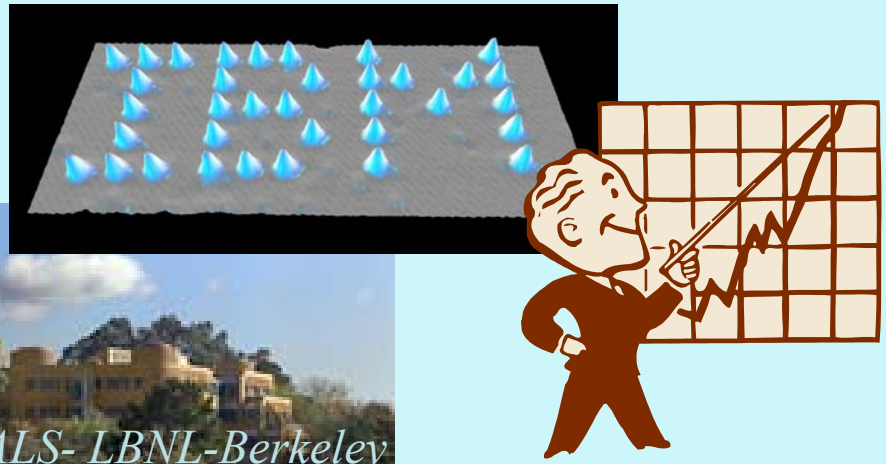
Diversify the Ph.D. Program

- **Discipline**
  - Science, Engineering & Medicine
- **Venue**
  - Academia, National Laboratory, Industry, Startups, Public Service
- **Culture**
  - Global societal and ethical impact
  - Input required from diverse population

Recent Addition: Tracks

- Academic "Tracks"
  - Tailor education to personal career goals
  1. Academia
  2. Federal/Non-Profit R&D Laboratory
  3. Industrial R&D
  4. Entrepreneurship/Startup





Tracks Determine …

- Courses
  - Pedagogy, Management, Public Policy, Entrepreneurship, Foreign Language
- Research Rotation
  - Industry, National Laboratory, International, UW TechTransfer, User Facility, etc.
- Non-academic Mentor
  - From career of interest

Diversify the Ph.D. Program

- **Discipline**
  - Science, Engineering & Medicine combine
- **Venue**
  - Academia, National Laboratory, Industry, Startups, Public Service
- **Culture**
  - Global societal and ethical impact
  - Input required from diverse population

Toward Cultural Diversity

- International Collaborations
  - Japanese National Institute for Materials Science
  - Korea Research Inst. of Standards and Science
- Ethical Research and Education
  - NNIN funding Public Health Grad Student
  - Require web-based Ethics Course
- Recruiting for Diversity
  - Actively seek diverse applicant pool
- Increase Communications
  - Among NT Students and Faculty
  - Between NT Pracititioners and General Public

“Optional” Essentials

- Communication amongst disparate groups
  - Nanoscience & Nanotechnology Student Association
  - Student-Run Seminar Series
  - Annual Workshop
  - Quarterly Dinners with Brief Presentations
- Outreach and Recruitment for Diversity
  - Individual PLUS Coordinated Efforts
- Career Planning
  - Mentorship and Internship Programs
  - Bring Non-academics to Campus
- Fellowship Program
  - Proposal writing experience
  - Bias toward Interdisciplinary Collaborations
  - Future: Fund Diversifying Research Rotations
- User Facility
  - Students are Trained Users AND become “Trainers” of Others

We Get Help …

- Participating Departments
  - Graduate Recruiting and Primary Advising
- UW Center for Nanotechnology
  - Administrative Infrastructure and User Facility
  - Fellowships
- NSF IGERT
  - Fellowships
  - Support for Seminars, Student Association, …
- UW-PNNL Joint Institute for Nanoscience
  - Collaborations on National-Need Problems
  - Intensive Short Courses and Annual Workshop
  - Fellowships
- National Nanotechnology Infrastructure Network
  - User Facility and Staff
  - Outreach and Societal and Ethical Impact Studies
- Center for Workforce Development
  - Mentoring Program
  - Summative Evaluations

Meeting Challenges in Nanotechnology Education

- Combine Depth and Breadth of Knowledge
  - "Standard" Ph.D. in Home Department
  - Interdisciplinary Courses, Research Rotation and Seminars
- Tailor Education to Individual Career Goals
  - Tracks for Academic, Gov't, Industry and Startup
- Novel Techniques using Expensive Equipment
  - User Facility and Ties to National Laboratory
- Prepare for Leadership in Multiple Venues
  - International, Government Laboratory and Industrial Opportunities
- New Field for Advisors, Students and the Public
  - Seminars, Outreach, Public Service

Doctor of Philosophy
in
“Home Department” and Nanotechnology

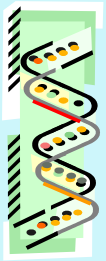
Knowledge

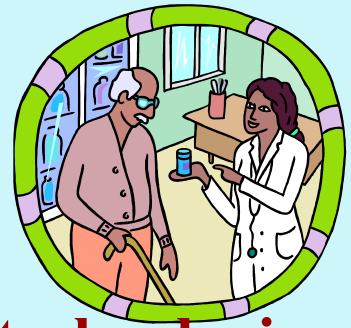
Novice

Expert

NT Workforce of Tomorrow

- Our Graduates Will:





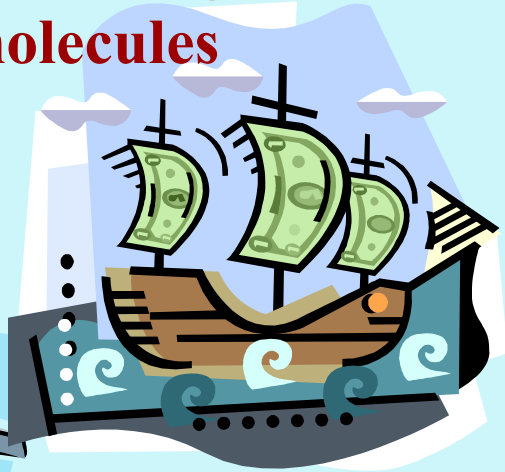
Build life-changing technologies from individual molecules

Interact across disciplines

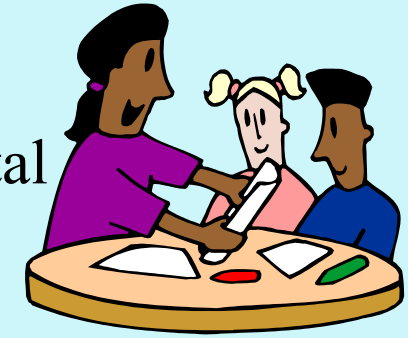
Inform public policy

Build new tools

Interact Globally



Raise Venture Capital



Teach the public

Path to the NT Dual Degree

Year 0 (at undergraduate institution):
- Learn about UW NT Ph.D. Program
- Participate in NNIN REU
- *Apply to UW home department*
- Apply for Early Bird Fellowship
- *Be accepted by home department*

Year 1 (at UW):
- *Core courses in home department*
- Attend NT informational meetings
- Investigate research options
- Early Bird research rotation

Year 2:
- *Departmental qualifying exam*
- *Complete home department course work*
- *Choose research home & supervisor*
- Interdisciplinary course work
- Apply for NT Dual Degree program
- Take "Frontiers in Nanotechnology"
- Attend NT Seminar, Join NaNSA
- Apply for IGERT fellowship/associateship
- Web-based ethics course

Year 3:
- *Define and begin thesis project*
- *General exam*
- Interdisciplinary coursework
- Research rotation or internship
- Attend NT seminar
- Career-related coursework
- IGERT fellowship/associateship
- Participate in NaNSA activities
- Participate in mentorship program

Year 4+:
- *Complete thesis research and dissertation*
- Attend NT seminar and/or present work at student NT seminar
- IGERT fellowship/associateship
- Present at annual CNT workshop and national meetings
- Internship/Short courses
- International/Exploratory rotation
- NaNSA & mentorship programs
- Work as NNIN "trainer"
- Explore career options & build network
- *Thesis defense and graduation*

Path to a UW Nanotechnology Ph.D.

University of Washington

Incoming Graduate Students

Admission into a "Home" Department

Arts&Sciences	Engineering	Medical School
Phys & Chem	BioE, ChemE, EE, Mat. Sci.	Biochem, BioE, Microbiology Genome Science, Physiol&Biophys

Fulfillment of all
Doctoral Requirements of Home Department

Dual Degree Program in Nanotechnology

Requirements:

Laboratory Rotations
Interdisciplinary Course Work
Research Thesis in Nanoscale Science and/or Nanotechnology
Frontiers in Nanotechnology
Nanotechnology Seminar

Options:

Competition for Graduate Student Awards in Nanotechnology
(funded by NSF-IGERT, UW-PNNL-JIN and the UW)
Hands-on Training and Research in the NanoTech User Facility
Membership in Nanotech Student Association
Mentoring Program
Industrial Internship and Research at PNNL

Graduation with
"Ph.D. in 'Home Department' and Nanotechnology"

Center for Nanotechnology

University of Washington, Seattle

Nanotechnology: where science fiction meets reality

"Every once in a while, a new field of science and technology emerges that enables the development of a new generation of scientific and technological approaches. Nanotechnology holds such promise."

NIH Workshop 2000

Nanotechnology is defined by the length scale at which scientists and engineers discover new phenomena, and engineer materials and devices.

A nanometer, one billionth of a meter, is about 10,000 times narrower than a human hair.

RESEARCH PROGRAMS

Materials that surround us

Exploit new nanoscale phenomena or learn from Nature how to assemble and engineer materials at the nanoscale. Integrate functions from nano to macro. Sense and respond to stimuli.

Devices that serve us

Use self-assembly approaches or nanofabrication tools to integrate biological or synthetic nanosystems into devices.

Knowledge that heals us

Use modern nanotools to learn more about the underlying causes of diseases, and how cells operate at the nanoscale. Develop new diagnostic kits and therapeutic procedures through the engineering of molecules and devices at the nanoscale. Understand the engineering design principles behind Nature's nanosystems. Do systems biology through bottom-up assembly.

COME AND JOIN US

Nanotech Seminar

Every Tuesday, 12.30-1.30 in Bagley Hall 260. The seminar is open to the public.

Nanotech Student Association

First and third Thursday of each month, 12.00 –1.00 in the New Chemistry Building 102

CENTER FOR NANOTECHNOLOGY since 1997

The Center for Nanotechnology brings together more than 55 faculty and their graduate students from the School of Medicine, and the Colleges of Arts & Sciences, and Engineering. It was established through the UW Initiative Funds. The participating departments include:

Biochemistry, Bioengineering, Chemistry, Chemical Engineering, Electrical Engineering, Genome Sciences, Materials Sciences and Engineering, Physiology and Biophysics and Physics

Our optional Ph. D. Program in Nanotechnology, the first of its kind in the United States, provides graduate students that have been admitted through the participating home departments with excellent interdisciplinary educational experiences in nanoscale science and nanotechnology.

As graduate student, take advantage of more than 40 graduate courses offered in Nanotechnology at the UW, analyze and manipulate nanoscale systems in our Nanotech User Facility, join our Nanotech Student Association to make friends with students in other departments, help organize seminars and nanotech events, collaborate with the Pacific Northwest National Laboratories through our PNNL/UW Institute in Nanotechnology, and get affiliated with academic or industrial mentors through the Center for Workforce Development.

Graduate Student Awards in Nanotechnology.

Take advantage of competitive fellowships funded through the NSF-Integrative Graduate Education and Research Training (IGERT) Program and the University Initiative Funds.

NANOTECH USER FACILITY (NUF)

Get hands-on training and advice in our Nanotech User Facility which houses state-of-the-art equipment to image and manipulate nanoscale systems. NUF is open to academic and industrial users and is operated as a cost center.

Equipment includes atomic force microscopy, optical microscopy, scanning electron microscopy and nanolithography.

Director:

David Castner, Department of Bioengineering

Co-Director:

Francois Baneyx, Department of Chemical Engineering

Deputy Director and Manager of the Nano User Facility:

Dong Qin, Ph.D.

Educatioon and Outreach Manager:

Ethan Allen, Ph.D.

For more information,

visit our website at www.nano.washington.edu

or call (206) 616-9760

come to the

University of Washington in Seattle

join the

Center for Nanotechnology

The University of Washington's Center for Nanotechnology has launched the nation's first doctoral degree program in nanotechnology, an undertaking designed to prepare students as leaders in a world in which scientific discovery and exploitation of nanoscale phenomena and the engineering of the very small will carry the next industrial revolution. You can enroll in the Nanotech program once you are admitted by one of the participating home departments. This program was made possible by a National Science Foundation's Integrative Graduate Education Research Training (IGERT) Award.

Financial Support in Nanoscience and Nanotechnology

We aim at recruiting the best graduate students and financially support them to pursue innovative research projects at the forefront of nanoscale science and technology. The fellowships provide annual support on a competitive basis.

Early Bird Awards in Nanotechnology offer starting graduate students financial support to join a research group of one of the participating nanotech faculty members during the summer quarter preceding the first academic year or for one quarter within the first year. Admission committees of the participating departments nominate the best candidates of their applicant pool for these awards, and the Center for Nanotechnology decides on the finalists.

National Science Foundation's Integrative Graduate Student Research Training (NSF-IGERT) Fellowship Awards are given to outstanding graduate students who have chosen research projects in nanoscale science or nanotechnology. Recipients need to be US citizens or permanent residents. Pendent on the annual competition, financial support from an IGERT fellowship, or IGERT and UIF combined, is limited to a maximum of three years**.**

Nanotechnology Graduate Research Awards support innovative graduate research projects in nanoscale science or nanotechnology through funding from the University of Washington Initiative Funds (UIF). The students need to have excellent academic records and apply competitively. Pendent on the annual competition, financial support is provided for a maximum of two years.

The University of Washington is committed to promoting respect for the rights and privileges of others, understanding and appreciation of human differences, and the constructive expression of ideas.

Nanotechnology is at the Core of other Affiliated UW Centers

University of Washington Biomaterials Engineering (UWEB)-
NSF Engineering Research Center, since 1995

Microscale Life Science Center (MLSC)-
NIH Center for Excellence in Genome Sciences, since 2001

Center for Materials and Devices for Information Technology Research (MDITR)-
NSF Science and Technology Center, since 2002

Get Experience Working with National Laboratories

To synchronize our efforts in nanoscale science and nanotechnology in the State of Washington, we have created the

Joint Institute of Nanoscience between the Pacific Northwest National Laboratories and the University of Washington, *since 2000*

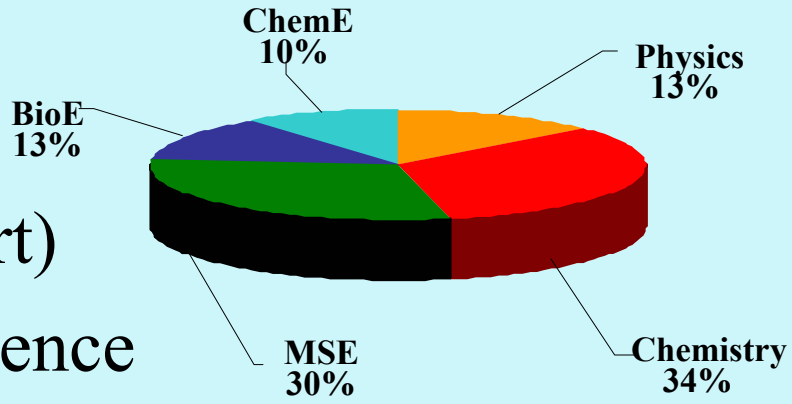
which provides you access to user facilities at PNNL, and financial support to work on joint research projects.

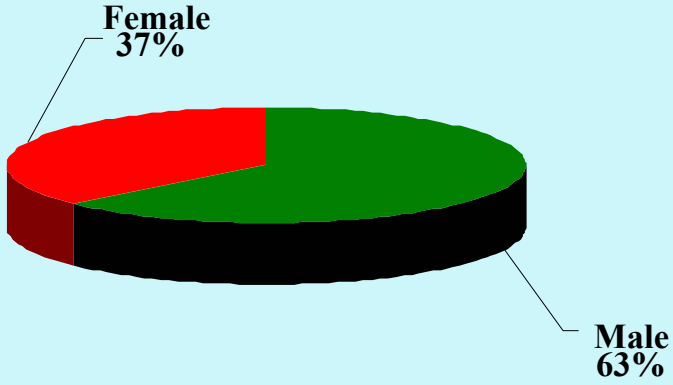
Join our Nanotech Student Association

Make friends in other Departments and build long-lasting professional relationships. The Nanotech Student Association (NSA) provides a forum for exchange of ideas between students from different disciplines. It plays a critical role in shaping the Center for Nanotechnology. NSA also nurtures interactions between industry and the university and invites distinguished seminar speakers. NSA members are furthermore heavily involved in all of our outreach activities.

Early Bird Fellowships

- Fellowships include:
  - One quarter RA in first year (including summer before start)
  - Travel to Nano-related conference
- Nominated by Departments
- Recruit Strong Students to UW
- Students who turn down EBF bring awareness of UW Nano-PhD to other institutions





2003 Nanotechnology Courses

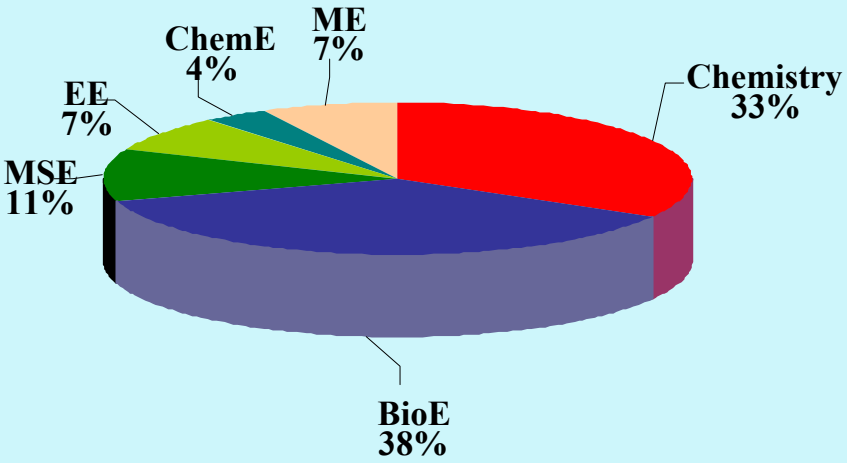
Nanoengineered Particles and Materials	o Polymeric materials o Molecular self-assembly at interfaces o Dyes as molecular probes o Surface chemistry and functionalization o Chemistry and physics of nanomaterials o Tribology and contact mechanics o Advanced processing of inorganic materials o Sol-gel processing o Theory of polymers o Solid-state physics of semiconductors o Solid-state physics o Condensed matter physics
Microfabrication & Nanofabrication	o Bioengineering applications in microfabrication o Solid-state laboratory techniques o Semiconductor devices and MicroElectroMechanical Systems (MEMS)
Analytical Tools to Probe Nanostructures	o Surface analysis o Spectroscopic characterization of organic molecules o Spectroscopic techniques for structural identification o Select topics in physics: scanning probe microscopy
Nanobiology	o Introduction to biomechanics o Lab techniques in protein engineering o Biomembranes: organic and bio-organic chemistry of nucleic acids and proteins o Protein machines: Mechanics of motor proteins and the cytoskeleton
Nanotech Applications	o Biosensors o Thin film science o Engineering and technology o Technologies for protein analysis

Filed Theses: First 1.5 Years

- Development of Microreactor Systems for Electrocatalytic Studies of Methanol Oxidation at Elevated Temperatures
- Nanoscopic Phase Transitions of Confined Thin Films Using Atomic Force Microscopy
- Engineering Surfaces for Directed Motion of Motor Proteins: Building a Molecular Shuttle System
- Surface Diffusion Parameters and Crystallization Kinetics for Amorphous Solid Water
- Self-Assembly Approaches to Nanostructured Materials
- Development and Synthesis of Luminescent Conjugated Copolymers and Their Fabrication into Polymer LEDs
- Development of Novel Conjugated Polymers for Light-Emitting Diodes
- Self-Assembly Approaches to Photonic Structures
- Design, Synthesis and Characterization of Organic and Polymeric Materials

Frontiers in Nanotechnology

- Annual team-taught course



2003 Student Population

Exposure to Diversity of UW Research

2003 Syllabus

Introduction	Vogel (BioE)
Nanotech User Facility, Soft Lithography and Dip-Pen Nanolithography	Qin (BioE)
Scanning Tunneling and Atomic Force Microscopy	Fain (Physics)
Single Molecule Spectroscopy	Dovichi (Chemistry)
Phase Separation in Self-Organized Systems	Keller (Chemistry)
Self-Assembled Thiol Films and Their Applications	Jiang (ChemE)
Optical Tweezers	Chiu (Chemistry)
Photonics	Dalton (Chemistry)
Environmental Molecular Science & Engineering Laboratory	Baer (PNNL)
Group Presentations (1-2)	Evaluations
Magnetic Nanomaterials	Frank (Chemistry)
Force-Regulated Molecular Recognition	Vogel (BioE)
Miniaturized Fuel Cells	Stuve (ChemE)
Nanowires & Nanoelectronics	Xia (Chemistry)
Semiconductor Nanocrystals: Synthesis and Physical Properties	Gamelin (Chemistry)
Grand Challenges in Biosensors	Yager (BioE)
Applications of Molecular Motors	Hess (BioE)
Cells in Micro/Nano-engineered Environments	Folch (BioE)
Group Presentations (3-6)	Evaluations
Group Presentations (7-8)	Evaluations

Graduate Fellowships

- Promote Interdisciplinary Projects
- Award (and inspire) Excellence
- Experience Writing Proposals
- Provide Vital Funding
  - National Science Foundation
    - IGERT Fellows *(44 to date)*
    - Early Bird Fellows (37)
  - University Initiative Fund
    - IGERT Associates *(40)*
  - UW-PNNL Joint Institute for Nanoscience
    - JIN Fellows
    - Also supports postdocs and faculty

Nanotechnology User Facility

- Nano-biology Node for NNIN
- Access to Essential Equipment
- Training on State-of-the-Art Equipment
- Place for Interactions

Current Positions of Graduates

- Postdoctoral Fellow in the Hoffman Group at Bioengineering, UW
- Postdoctoral Fellow in the Whitesides Group at Chemistry, Harvard
- Postdoctoral Fellow in the Knoll Group at Max-Planck-Institut für Polymerforschung *(NSF Mathematical and Physical Sciences Distinguished International Postdoctoral Research Fellowship, 2003-2005)*
- Staff Scientist, Intel, Albuquerque, NM
- Postdoctoral Fellow in the Vogel Group at Bioengineering, UW
- Postdoctoral Fellow in the Whitesides Group at Chemistry, Harvard
- Senior Scientist, Isis Pharmaceuticals, Carlsbad, CA
- Assistant Professor, Biomedical Engineering, Georgia Institute of Technology, Atlanta, GA
- Postdoctoral Fellow in the Wolf Group at Physics, Freie Universitaet Berlin *(Alex. von Humboldt Postdoctoral Fellowship)*
- Staff Scientist, Scripps Research Institute, San Diego
- Postdoctoral Fellow in the Jen Group at Materials Science and Engineering, UW
- Postdoctoral Fellow in Nanomix Inc., CA
- Staff Scientist, Symyx Technologies, Santa Clara, CA
- Acting Assistant Professor, University of Puget Sound, Tacoma, WA