Innovative Approaches to Challenges in Undergraduate Nanoscience Education

Ethan Allen

Center for Nanotechnology &

Genetically Engineered Materials Science and Engineering Center

University of Washington, Seattle

ethana@uw.edu 206-616-9760

GENETICALLY ENGINEERED MATERIALS SCIENCE & ENGINEERING CENTER

NSF-MRSEC AT THE UNIVERSITY OF WASHINGTON

THE CENTER FOR NANOTECHNOLOGY AT THE UNIVERSITY OF WASHINGTON

Two Challenges (among many):

1. How to provide sufficient hands-on experiences for a regular undergraduate laboratory class (of ~30 students), enabling all students to learn first-hand how to use different types of instruments to visualize nanoscale features and characterize nanoscopic samples.
2. How to provide undergraduate students with nanoscale science and technology education that is sufficiently deep so as to be useful, connected to other science learning so as to be meaningful, and broad so as to be applicable for their future learning.

Two Solutions:

1. **NUE UNIQUE** – Using Nanoscience Instrumentation for Quality Undergraduate Education (funded via NSF's Nanotechnology for Undergraduate Education program)

2. **NUE NME Minor** - Minor in Nanoscience and Molecular Engineering (submitted to NSF's Nanotechnology for Undergraduate Education program)

Challenge 1:

How to provide sufficient hands-on experiences for a regular undergraduate laboratory class (of ~30 students), enabling all students to learn first-hand how to use different types of instruments to visualize nanoscale features and characterize nanoscopic samples.

Solution:

NUE UNIQUE

http://depts.washington.edu/nanolab/NUE_UNIQUE/NUE_UNIQUE_Workshop.htm

(Or just Google “NUE UNIQUE”)

NUE – UNIQUE

Nanotechnology for Undergraduate Education (NUE) NSF 0634088

Using Nanoscience Instrumentation for Quality Undergraduate Education

University of Washington (UW)

René M. Overney (ChemE)

David Ginger (Chemistry)

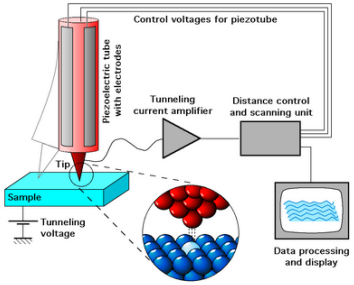
Mehmet Sarikaya (Mat. Sci.)

North Seattle Community College (NSCC)

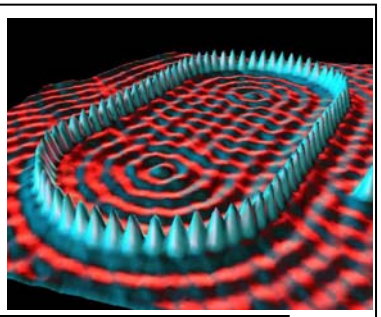
Thomas W. Griffith

In partnership with:

- Genetically Engineered Materials Science and Engineering Center (GEMSEC), an NSF-Materials Research Science and Engineering Center (MRSEC)
- **Nanosurf AG, Liestal/Switzerland and nanoScience Inc., Phoenix, AZ**
- Center for Nanotechnology (CNT) at the University of Washington



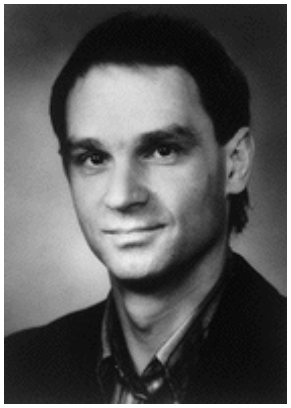
Birth of Nanoscience and Nanotechnology



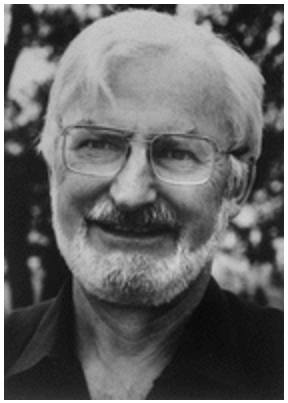
The invention of the Scanning Tunneling Microscope (STM) in Zurich in 1981 marked the birth of nanoscience and nanotechnology.

(The Economist "No Boundaries" Innovation Award in San Francisco (2004) to G. Binnig, Ch. Gerber, H. Roher)

Nobel Prize in Physics 1986
The prize was awarded half to:
ERNST RUSKA for his fundamental work in electron optics, and for the design of the first electron microscope,
and half to:
GERD BINNIG and HEINRICH ROHRER for their design of the scanning tunneling microscope.



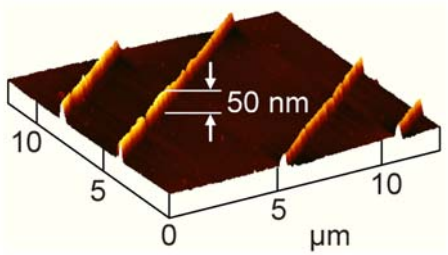
G. Binnig

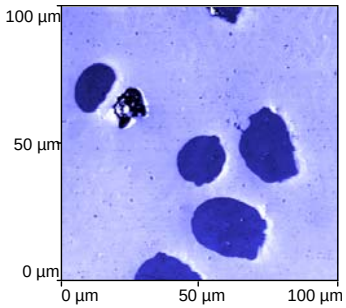


H. Rohrer

Scanning Force Microscopy (SFM)

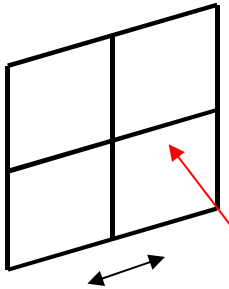
NUE UNIQUE



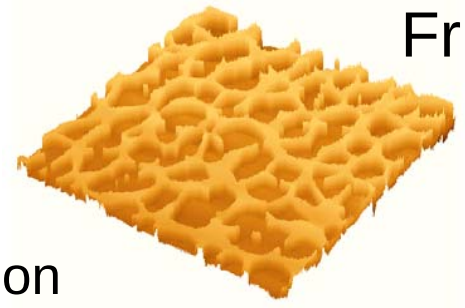


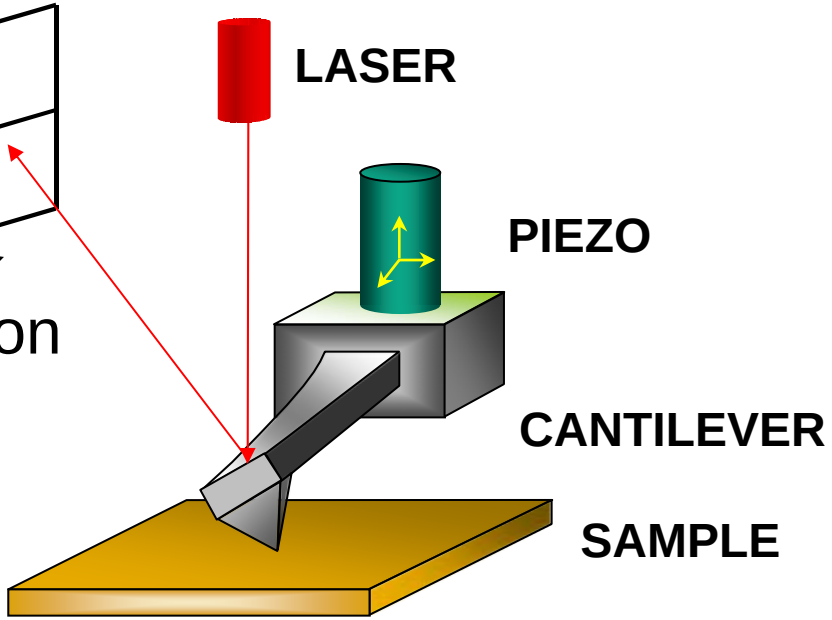
Material Distinction

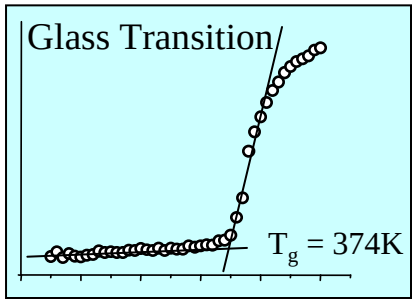
Topography



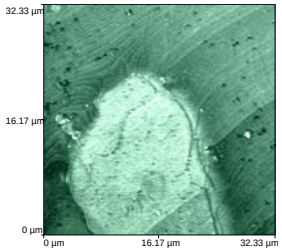
Friction



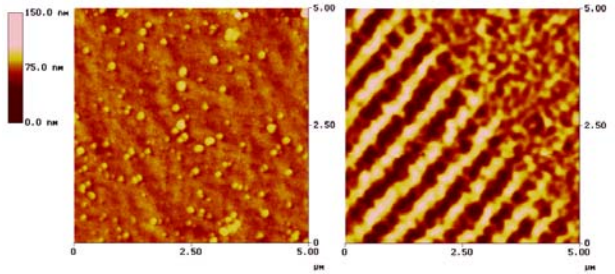




Phase Shifts



Elasticity



Magnetism

The Instrument

SPM: *Nanosurf easyScan 2*

Microscope (SFM)

Laptop (USB connected)

Electronics

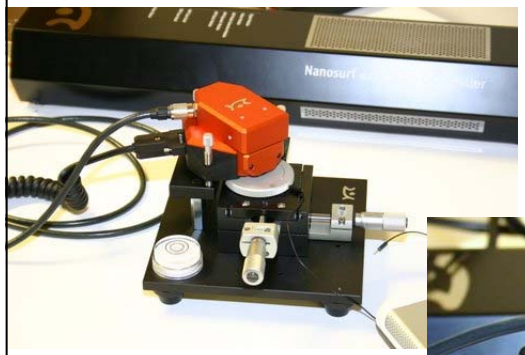
Signal Input/Output Box

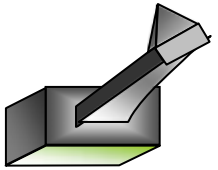
Vibration Isolation

The Instrument

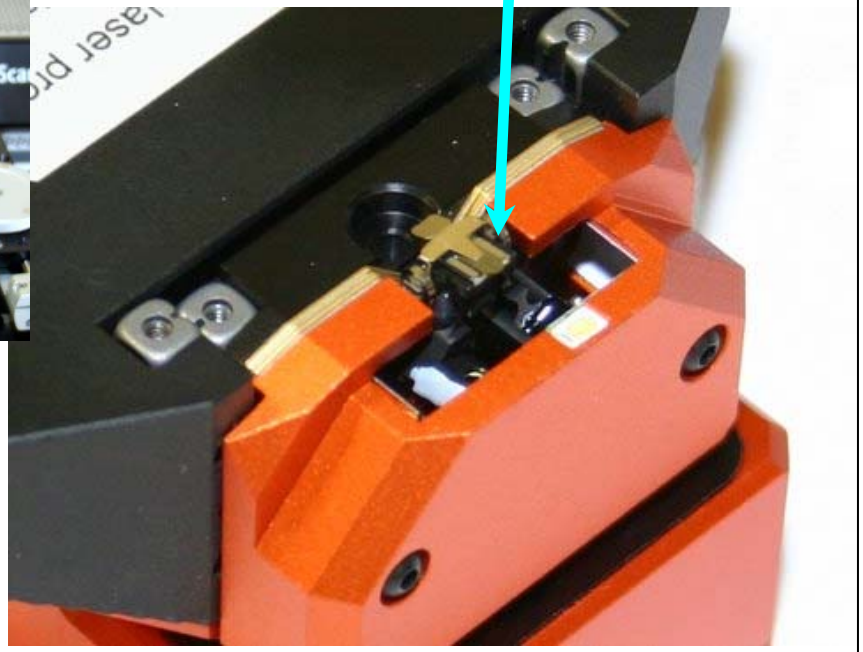
The Instrument

SPM: *Nanosurf easyScan 2*





SFM Probe: Cantilever



Program Accomplishments

Over the past two years, NUE UNIQUE has developed an effective nanoscience teaching model by:

- **Introducing a coherent program with focus on fundamentals that fit into the core program of many engineering and natural science disciplines**
- **Providing true hands-on experience with top-notch portable equipment in an authentic undergraduate laboratory setting**
- **Establishing a transferable and mobile model adaptable by most educational institutions. It is the mobility and transferability that makes this program unique.**

→ ***The model is based on leasing vs. owning SPMs*.**

→ ***Multiple SPMs are available for a class, reducing the number of students per instrument, and enabling greater individualized hands-on learning and exploration.***

Nanoscience on the Tip

Week-long Laboratory SPM Workshop

Open to upper division UGs at 4 year institutions, and senior community college students with prior engagement in nanoscience/nanotechnology.

- **Students gain hands-on experience involving a wide variety of nanotechnology/nanoscience applications, *e.g.*,**
  - nanoscale interaction force measurements
  - visualization and characterization of biological tissue and membranes
  - thermomechanical probing
  - investigation of photovoltaic materials and lithography

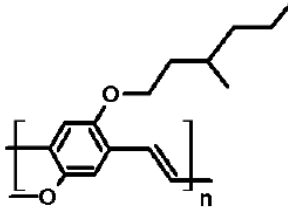
- **Students are trained in the use of various SPM modes, in particular**
  - Scanning Tunneling Microscopy (STM)
  - Scanning Force Microscopy (SFM) (*"Atomic Force Microscopy"*)
  - Electrostatic Force Microscopy (EFM)

The workshop has multiple SPM systems (5), with an instrument to student ratio of ~1:4. At the end of the course students can operate the three widely used SPM tools: STM, SFM and EFM.

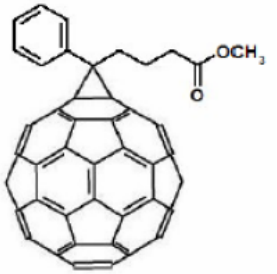
Lab Modules:

Six examples of independent lab modules using Nanosurf's Easy Scan 2 SFM and STM

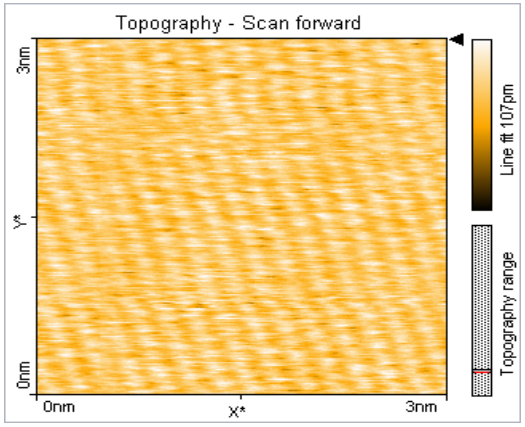
Lab Module 1 – ***Electronic Constraints***: Electronic constraints in blended conjugated polymer films *(right)* are imaged with AC-mode electrostatic force microscopy (EFM), illustrating electric field variations in complex organic molecular systems that have potential in electro-optics and photovoltaics.



MDMO-PPV



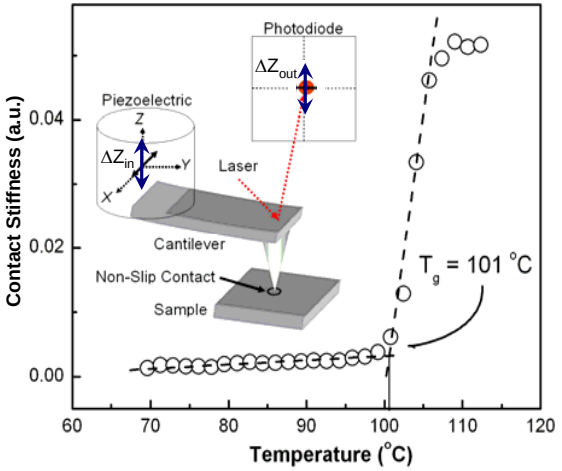
PCBM

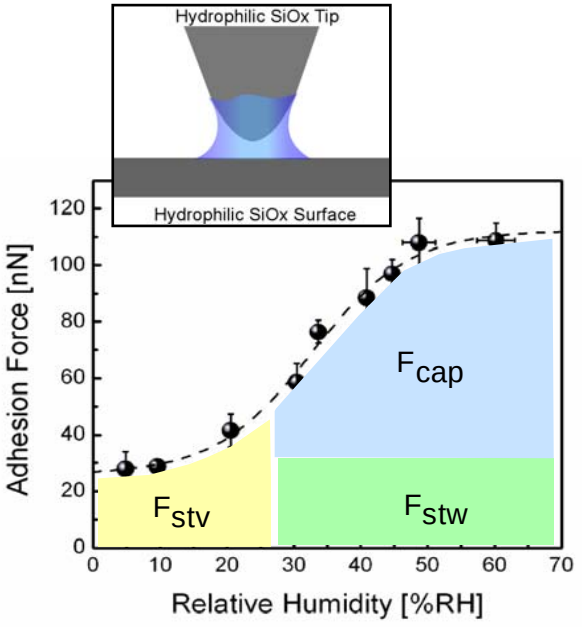


Lab Module 2 – ***Electronic/Structural Constraints***: Scanning Tunneling Microscopy (STM) and Spectroscopy (STS) provide atomistic scale perception and illuminate molecular scale concepts of surface electronic properties and the tunneling effect. *(Left)* Student data showing atomic resolution on graphite from STM.

Lab Modules (continued)

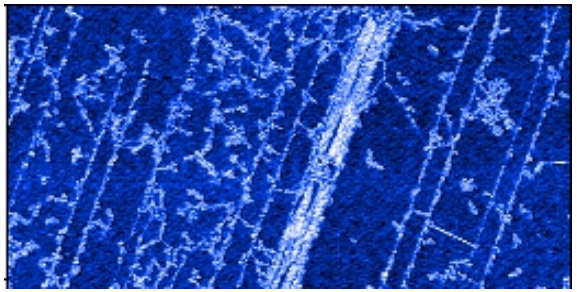
Lab Module 3 – ***Interfacial/ Rheological Constraints***: Force/distance modulated scanning force microscopy (SFM) enables exploration of thermomechanical properties in ultrathin polymer films around the glass transition.
(Right) Glass transition of polystyrene.

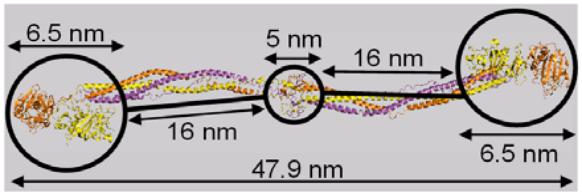




Lab Module 4 – ***External Force Constraints***: SFM force spectroscopy shows the dominating effect of capillary force over local Van der Waals interactions in a humidity controlled environment.
(Left) Student data on the contribution of capillary forces F_{cap} and Van der Waals forces (F_{stv} and F_{stw}) to overall adhesion pull off forces as function of the relative humidity.

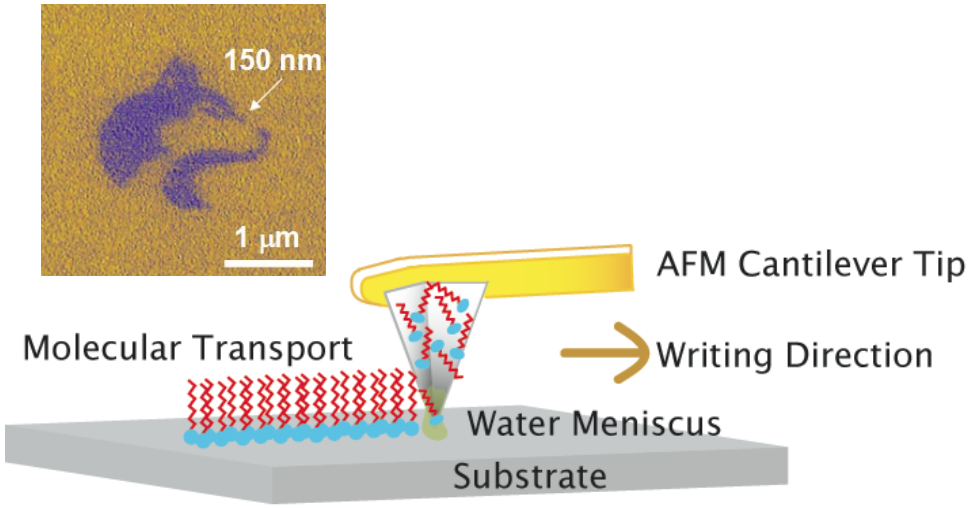
Lab Modules (continued)





Lab Module 5 - ***Interfacial Mobility and Molecular Binding Kinetics***: The concept of adsorption kinetics is examined with non-contact force microscopy, using proteins and an SFM operated in a liquid environment.
(Left) Fibrinogen on graphite and its structure.

*Lab Module 6 – **NanoLithography**: Dip-pen nanolithography (DPN) highlights engineering aspects of lithography.*



Example of Logistical Organization: 5 Lab Units & 4 Groups of Students

Lab Units and Teaching Assistants

Lab Unit:	Description	Teaching Assistant(s)
1	SFM Basics and Nanolithography	all
2	Electrostatic Force Microscopy	Yeechi Chen
3	Force Displacement Analysis	Dan Knorr
4	Force Modulation Analysis	Jason Killgore
5	Scanning Tunneling Microscopy	Joseph Wei and Chris So

Lab Assignments for each Group of Students: Tuesday to Friday

(Lab Unit 1 for all Groups carried out on Monday)

	Tuesday	Wednesday	Thursday	Friday
Lab Unit 2	Group 1	Group 4	Group 3	Group 2
Lab Unit 3	Group 2	Group 1	Group 4	Group 3
Lab Unit 4	Group 3	Group 2	Group 1	Group 4
Lab Unit 5	Group 4	Group 3	Group 2	Group 1

Daily Schedule

Monday	Tuesday	Wednesday	Thursday	Friday
June 25	June 26	June 27	June 28	June 29
	8:00 a.m. SFM Lecture on Surface Electronic Properties *Prof. Ginger* Mueller 154	**8:00 a.m.** SFM Lecture on Contact Mechanics *Prof. Overney* Mueller 154		**8:00 a.m.** **Work on the assigned Lab Unit for the day**
9:00 a.m. **Welcome** *Profs Overney & Sarikaya* (GEMSEC) Mueller 154	**9:00 a.m.** **Work on the assigned Lab Units for the day** **(a) Prelab Assignment** **(b) Lab Assignment** **(c) Lab Report** (start with the lab report around 2 p.m.)			**(a) Prelab Assignment** **(b) Lab Assignment** **(c) Lab Report** (start with the lab report around 1 p.m.)
9:15 a.m. **Lab Overview** *Prof Overney* Mueller 154				
10:00 a.m. **Laboratory** **UNIT 1:** **Introduction to SFM and Nanolithography** Wilcox 233 and 335	Wilcox 233 and 335			**2:30 p.m.** **Final Discussion** **Certificates and Awards** **Evaluation** Mueller 170 **3:30 p.m.** **Adjourned**
4:30 p.m. Daily discussion about the lab Milnor-Roberts Room				
Individual preparation for the assigned Lab Unit the next day: Involves reading of the background information and answering the theoretical questions. Due at the beginning of the lab the next morning.				

Challenge 2:

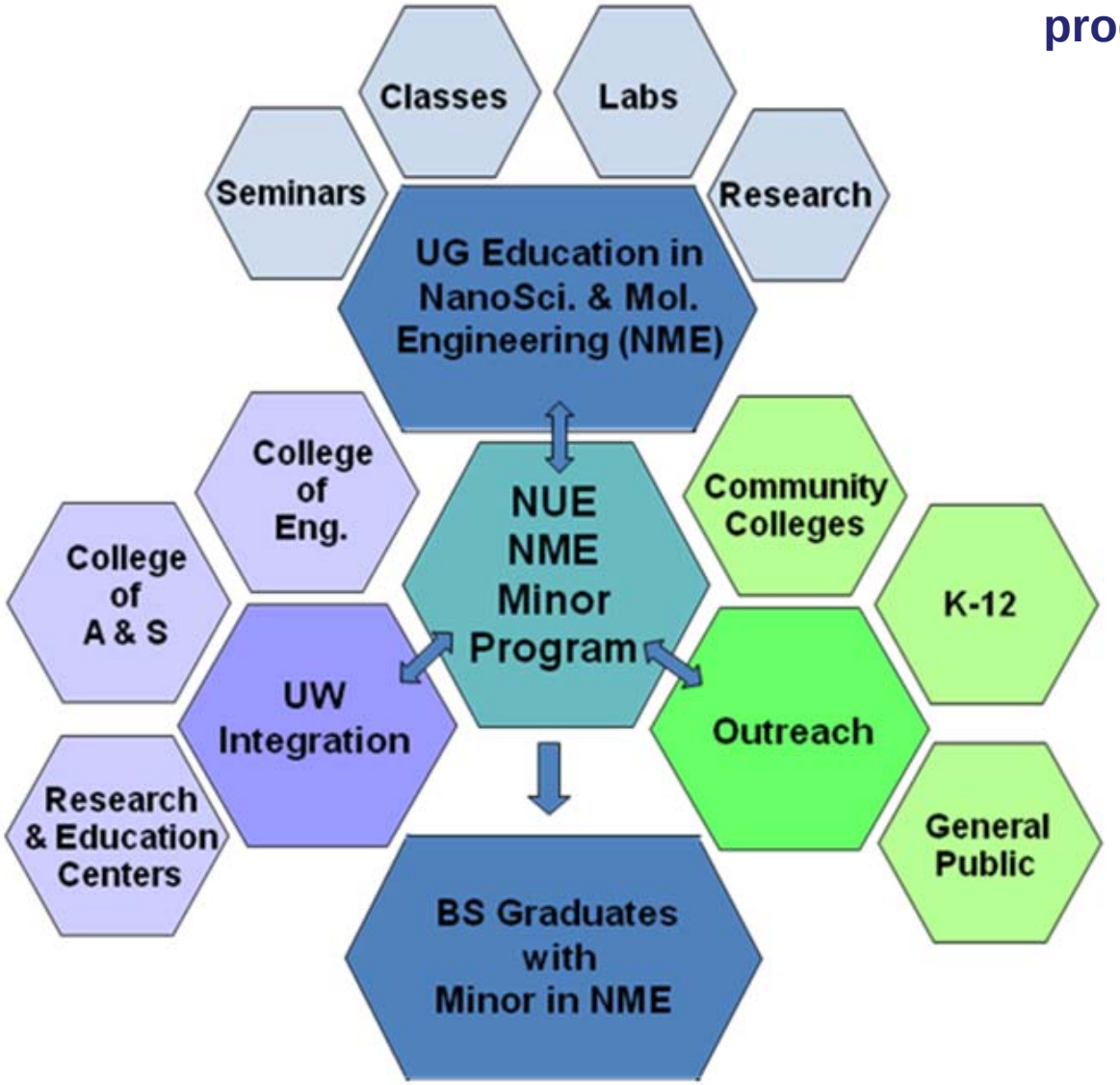
How to provide undergraduate students with nanoscale science and technology education that is sufficiently deep so as to be useful, connected to other science learning so as to be meaningful, and broad so as to be applicable for their future learning.

Solution:

NME Minor

(Submitted to NSF's NUE program in April, 2009)

Proposed Minor in Nanoscience and Molecular Engineering



Independent, multi-disciplinary program within CoE & CoA&S

Steering Committee:
PI, Renee Overney
co-Pis:
Karl Bohringer
Mehmet Sarikaya
Marjorie Olmstead
Philip Reid
plus
Ethan Allen

Advisory board with representatives from:
11 participating departments
2 community colleges
CoE & CoA&S
plus
Evaluator

Model: UW's Dual Ph.D. in Nanotechnology Program

- First Ph.D. degree in nanotechnology in the nation – started in 2001
- Core philosophy: Combine depth in a single discipline with breadth in nanoscale science and technology.
- Students from ten participating departments: Biochemistry, Bioengineering, Chemical Engineering, Chemistry, Electrical Engineering, Genome Sciences, Materials Science & Engineering, Microbiology, Physics, Physiology & Biophysics
- Depth from requirements for Ph.D. in home department
- Breadth from Nanotech Ph.D. option requirements:
  - > 'Frontiers in Nanotechnology' course
  - > Four quarters of nanotechnology seminars
  - > Three (two outside home dept.) additional 'nanotechnology-relevant' courses
  - > Laboratory rotation outside of advisor's home department
  - > Thesis research that is 'nanotechnology-relevant'

Upon completion a dissertation on an approved topic in nanoscale science and/or technology (with at least 2 CNT faculty on the supervisory committee), students receive a dual degree in "*Home Department* and Nanotechnology"

Minor in Nanoscience and Molecular Engineering

UW Stakeholders:

Colleges: Engineering; Arts & Sciences

Departments:

Aeronautics and Astronautics
Bioengineering
Biology
Chemical Engineering
Chemistry
Civil and Environmental Engineering
Computer Science and Engineering
Electrical Engineering
Mechanical Engineering
Materials Science and Engineering
Physics

***Centers*:**

Center for Nanotechnology (CNT)
Genetically Engineered Materials Science & Engineering Center (GEMSEC)

Community Stakeholders:

Edmonds Community College
North Seattle Community College

NME Minor - Goals

(1) Develop, test, evaluate, and integrate within existing UG laboratory courses a set of ten diverse laboratory modules that form a model state-of-the-art UG Teaching Laboratory in Nanotechnology and Molecular Engineering.

(2) Initiate and develop a framework for the NME Minor program within the two colleges for the named 11 departments.

(3) Establish a permanent home for the NME Minor program that will furnish student advising and program coordination campus-wide.

(4) Review and refine curricula, integrating nanoscale and molecular engineering perspectives to provide:

(a) students with grounding in the field and an appreciation for a cross-disciplinary approach based on fundamentals that are common to multiple disciplines, and

(b) departments with the ability to expand their programs in nanoscale science and molecular engineering easily.

(5) Work with community college partner institutions on integrating and aligning nanotechnology educational programs across institutions.

Goal 1

NME Laboratory Modules

1. Mie Scattering from Metallic Nanoparticles
2. Synthesis of CdSe and ZnO quantum dots
3. Optical Properties of Semiconductor Quantum Dots
4. Fluorescence intermittency from nanoemitters
5. Control of Stability in Colloidal Suspension via Short-Range Van der Waals Interaction
6. Molecular Mobility Analysis in Condensed Organic Systems
7. Microfluidics in PDMS
8. Building Nanomotors and Logic Gates with DNA
9. Biomolecular Adsorption on Solids
10. Bionanomaterialization

Goal 2

NME Core Course Framework

Table 3: NME Courses (*shaded area*: To be developed/initiated during the funding period of NME Minor)

Freshman	**Sophomore**	**Junior**	**Senior**
FSS-197 - Freshmen Sem. Series: Nanosci. and Molecular Engineering (1) (planned for 2010)	**NME 221** Frontiers of Nanosci. and Molecular Engineering (1) (planned for 2011)	**NME 321** Frontiers of Nanosci. and Molecular Engineering (1) (planned for 2012)	**NME 421** Frontiers of Nanosci. and Molecular Engineering (1) (planned for 2013)
	ChemE 220 / NME 220 Introduction to Molecular and Nanoscale Principles (4) existing course → NUE UNIQUE)	**NME 320** Nanoscience and Molecular Engineering (4) (new development – planned for 2010)	**NME 420** Nano-Ethics (3) (currently under development. Adapted and tailored towards NME Minor)
		NME 322 Nanosci. and Molecular Eng. Lab (3) (based on Lab Module Developments)	**NME 422** – UG Research in NME (3) (consolidated towards NME Minor)

27 credits, with 9 being departmentally specific

Goal 2

NME Courses

- FSS 197 (1 credit): **"Freshman Seminar in NME."** (to be developed) Fosters awareness of nanotechnology, introduces students to research and educational opportunities in nanotechnology on campus, and provides a first intellectual platform for nanotechnology-interested students to meet.

- NME 220 (4 credits): [Adaptation of ChemE 220] **"Introduction to Molecular and Nanoscale Principles."** Introduces nanotechnology and nanoscience based on fundamental principles: macroscopic limits of material properties and molecular structures, interaction forces, molecular transport properties, thermodynamic principles, cooperative and nanoscale phenomena, and device and process technologies.

- NME 221/321/421 (1 credit each): **"Frontiers of Nanoscience and Molecular Engineering."** Seminar series - presentations of student research and capstone projects; connects students with on-going progress in nanotechnology, and provides a platform to meet and share their learning experiences.

Goal 2

NME Courses (continued)

- NME 320 (4 credits): **"Nanoscience and Molecular Engineering"** (to be developed) Connect fundamental aspects of nanoscale science with device and system applications. In five two-week segments, students will explore nanotechnology and modern product development in molecular engineering, biomimetic engineering, nanothermodynamics and nanoparticle synthesis, electronic transport and nanoelectronic circuits, and finite size device applications involving quantum phenomena.

- NME 322/422 (3 credits each): **"NME Laboratory"** and **"Research in NME."** (to be developed) Provide UG research experience and Departmental Capstone Design Projects.

- NME 420 (3 credits): **"Societal and Ethical Issues in NME."** (Under development via NSF's *Nano-ethics on the World Wide Web: Helping Faculty Enhance Graduate Education*) Introduce students to thinking beyond the laboratory and classroom to the potential impact of NME on society.

Goal 3

NME Home: UW's new *Institute for Molecular Engineering*

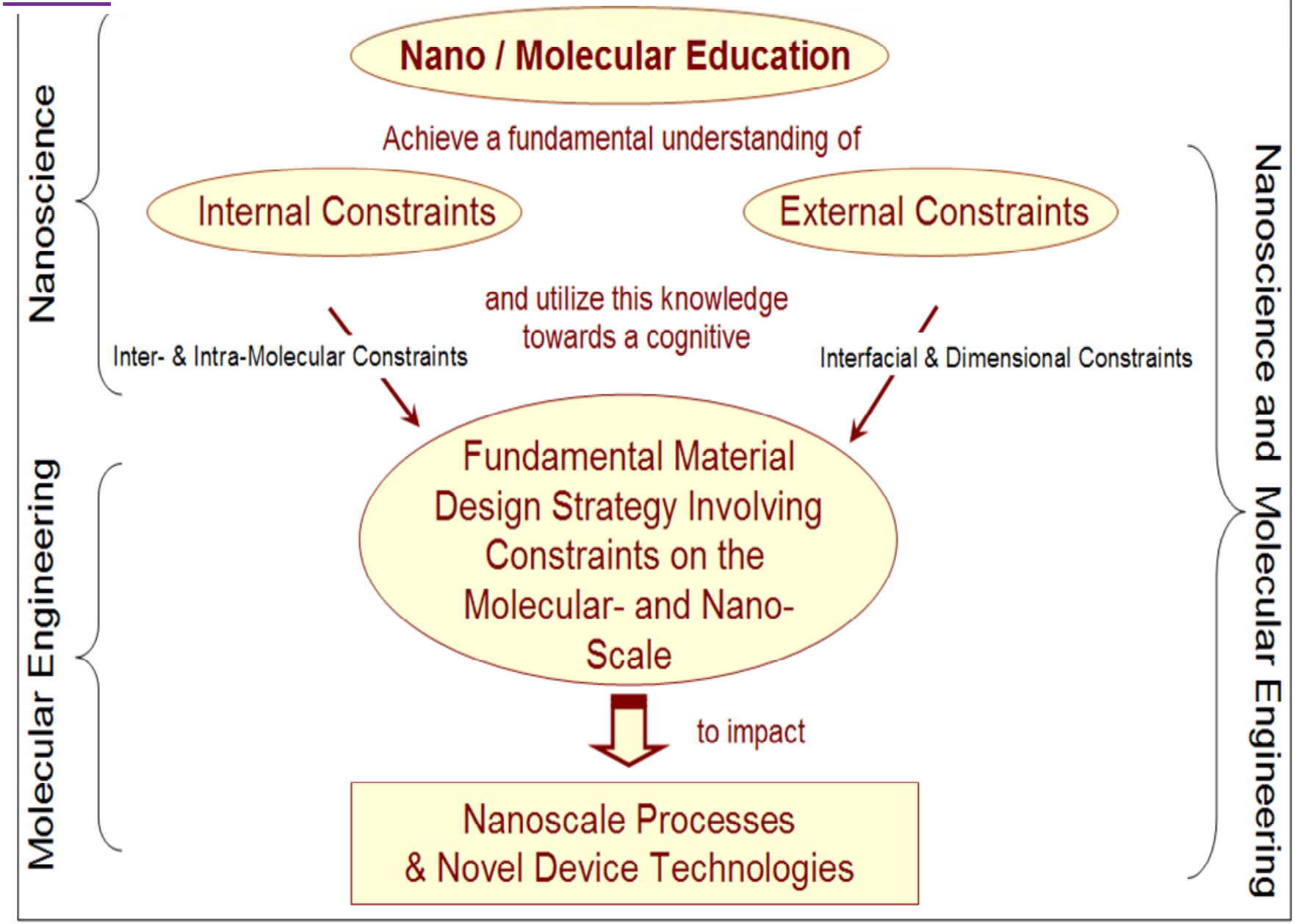
- **$155M+ to create world-class molecular engineering research program**
- **Molecular Engineering Working Group formed in January of 2007; surveyed opportunities, needs, synergies, & addressed organizational fit at UW**
- **Planning 160,000 sq ft interdisciplinary building**
- **WA legislature approved $62.5M**
- **UW to issue bonds for $16M**
- **Preliminary and schematic design work completed**
- **Mol. Eng. building designated top infrastructure priority by WA Governor & UW President**
- **First phase of construction to be completed 2009-2011**

Goal 4

Classification of Nanotechnology

Perspective	*Scheme*	*Elements/Aspects*
Nanomaterials	Number of Dimensions 1,2, and 3 dimensional	Nanoparticles, Nanopores Nanotubes, Nanofilaments Mono-, multi layered, and thin films
Nanomanufacturing	Fabrication Methods Top Down, Bottom Up	Milling, lithography, machining Vapor phase and liquid phase deposition methods, solid-state routes
Nanoscience	Constraints - Internal and External, - Thermo/Statistical/Rheological, - Electronic/Structural	Inter- and intramolecular constraints, and interfacial and dimensional constraints Enthalpic, entropic, organizational, transitional, relaxational, fluctuational constraints Quantized transport, mobility, fluctuations, interactions

Goal 4


Nanoscience
Molecular Engineering
Nanoscience and Molecular Engineering
Nano / Molecular Education
Achieve a fundamental understanding of
Internal Constraints
External Constraints
and utilize this knowledge towards a cognitive
Inter- & Intra-Molecular Constraints
Interfacial & Dimensional Constraints
Fundamental Material Design Strategy Involving Constraints on the Molecular- and Nano-Scale
to impact
Nanoscale Processes & Novel Device Technologies

Goal 5

Integrate With Existing Community College Programs

Edmonds Community College - National Resource Center for Materials Technology Education (MatEd):

- Fostering national network of industry and educational professionals to increase number and diversity of highly skilled technicians ready for employment
- Resource Center w/ curricula for materials technology program enhancement and improvement at community and technical colleges nationwide
- Developed and published core competencies needed by today's technicians that handle materials

North Seattle Community College:

- First WA Associate of Applied Science-Transfer degree (AAS-T) in Nanotechnology
- Cross-disciplinary program w/ elements of material science, chemistry, biology, physics, engineering, and electronics
- Provides technicians solid foundation in science and trains students in use of nanotechnology instrumentation

To align these programs with NME Minor through an articulation agreement

Wrapping Up

1) ***Most important lessons about nano-education at the undergraduate level:***

   A. **Offerings must align with existing courses and curricula**
   B. **Materials must be accessible with clear benefits and applications in existing disciplines**

2) ***Most critical challenges facing undergraduate nano-education:***

   A. **How to balance interdisciplinary breadth with discipline-specific depth**
   B. **How to simultaneously provide a comprehensive perspective along with deep discipline-specific content within confines of a typical university course**

3) ***Future for nano-higher education holds:***

   A. **Web-based, self-guided, self-paced learning opportunities that incorporate comprehensive breadth with discipline-specific depth**
   B. **Discipline-based labs that build on, support, and complement web tools**