Building Leadership for the Nanotechnology Workforce of Tomorrow:

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

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“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....
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 $[\text{frontier } - \varepsilon]$ to $[\text{frontier } + \varepsilon]$

• 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

Read other people’s ideas

Analyze Data (and email…)

Present work

Take Data

GRADUATE

Publish results
“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:
  
  Build life-changing technologies from individual molecules
  
  Interact across disciplines

  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


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

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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.
Nanotechnology Ph.D. Program
University of Washington

Participating Departments
Program History

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

NT Graduates

- Mat Sci 37%
- BioEng 6%
- Chem Eng 19%
- Physics 19%

Current Students

- Chemistry 37%
- Physics 14%
- Mech Eng 11%
- BioEng 16%
- Chem Eng 5%
- Elec Eng 14%
- Mat Sci 3%
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 Practitioners 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

Novice

Knowledge

Expert
NT Workforce of Tomorrow

- Our Graduates Will:
  - Interact across disciplines
  - Inform public policy
  - Build new tools
  - Interact Globally
  - Teach the public
  - Raise Venture Capital
  - Build life-changing technologies from individual molecules
### 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 coursework
- 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**

- Engineering: BioE, ChemE, EE, Genome Science, Physiol&Biophys
- Medical School: Biochem, BioE, Microbiology, Frontiers in Nanotechnology

**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”
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.
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.

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.

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.
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

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

<table>
<thead>
<tr>
<th>Department</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>BioE</td>
<td>38%</td>
</tr>
<tr>
<td>ChemE</td>
<td>4%</td>
</tr>
<tr>
<td>EE</td>
<td>7%</td>
</tr>
<tr>
<td>ME</td>
<td>7%</td>
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<tr>
<td>MSE</td>
<td>11%</td>
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</tbody>
</table>

### 2003 Syllabus

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

**Exposure to Diversity of UW Research**
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