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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.

INTRODUCTION

NANOTECHNOLOGY has been the fabric of dreams, until recently. Availability of novel technologies in the last decade have made it possible to analyze and manipulate synthetic and biological systems at the level of single atoms, molecules and supramolecular assemblies. The exploitation of the unique properties and phenomena of matter at the nanoscale (1–100 nm) has triggered a revolution in the forefronts of science, engineering and medicine. Far-reaching outcomes for the 21st century are envisioned in scientific knowledge and in a wide range of technologies, including information technology, healthcare, materials, energy and environment. Revolutionary advances in environmentally sustainable technologies and health care are urgently needed, especially considering that the world population will likely grow to over 10 billion in the next century.

By virtue of the interdisciplinary nature, rapid advances in nanoscale science and engineering can only thrive in a collaborative environment where faculty and students from different disciplines discuss ideas, collaborate and share their expertise. In most disciplines, however, education has progressed in the past by first laying a foundation and then building pyramids of knowledge step by step. This approach to education has resulted in a highly specialized workforce. It has promoted enhanced departmentalization in academia, each field imprinting its own way of thinking on its scholars and evolving its own languages and acronyms. The level of specialization has progressed over the decades. Specialization often deepens the trenches between disciplines to such an extreme that publications often became incomprehensible to scholars outside the field. Such a divergence in science makes it difficult for one discipline to capitalize on the advances of another.

The discovery of new analytical tools to visualize and manipulate single atoms, however, has marked a turning point from divergence to convergence within the scientific community [1–4]. With atomic force microscopy, optical tweezers and single molecule spectroscopy at hand, scientists and engineers in a variety of fields have started to explore the nanoscale world. The frontiers of many disciplines, including physical sciences, biosciences and engineering, have started to converge at the nanoscale, and nanotechnology has begun to thrive from this interdisciplinary cross-fertilization [1–4]. Innovations in nanoscale science and technology will require an intimate marriage of diverse fields, from theory to application, wherein each one learns from the other, and all learn from nature's tool chest in nanotechnology.

Since nanotechnology encompasses a variety of disciplines, including the physical sciences, engineering and biomedicine, an educational system focusing on single disciplines will not provide an adequate training to graduate students. Already at the graduate level, researchers and engineers need to learn the vocabulary and common tools of the other disciplines. They need to be able to communicate and appreciate each other's successes. This facilitates that a breakthrough in one field is rapidly picked up and merged with technology developed in other disciplines. Engineers need to learn from molecular scientists, and molecular scientists have to discover the engineering principles that control the behavior of molecules and self-assembled supramolecular structures.

Yet, it will remain essential to the vitality of this emerging field of nanotechnology that challenges be tackled from different perspectives, by people who communicate well but have different mindsets and expertise. Concerted efforts from scientists, engineers and the medical profession will be

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required. Training graduate students so that they can communicate across such boundaries and at the same time have great depth in selected core area(s) is essential [5–9].

Considering the multidisciplinary fabric of nanotechnology, we thought that introducing a stand-alone degree programs in nanotechnology where students get an overview of many disciplines, but none in sufficient depth to make major contributions, will not give our students the training they need to meet the future challenges. Instead, we put in place an 'optional' Ph.D. program in nanotechnology at the University of Washington, Seattle, which is tied closely to other science disciplines. (See [10] for an earlier description of this program.)

Nine departments from the three colleges are taking part, and students will earn concurrent degrees in nanotechnology and in a discipline of science, engineering or medicine. The departments include

- Physics
- Chemistry
- Materials Science and Engineering
- Chemical Engineering
- Electrical Engineering
- Molecular Biotechnology (now Genome Sciences)
- Biochemistry
- Physiology and Biophysics
- Bioengineering.

They are in the Colleges of Arts & Sciences, Engineering, as well as in the Medical School funded through a $2.7 million grant from the National Science Foundation's Integrative Graduate Education Research Training program (NSF-IGERT) NSF-IGERT award in 2000, our graduate students will receive an in-depth education in one of nine participating home departments, while they gain early exposure to the other disciplines through additional course work, joint seminars, and by being co-mentored across departmental lines.

The goal is that once they leave the program, they will still think like physicists, chemists, biologists or engineers, yet they will have developed enough awareness of other disciplines such that they can capitalize of their progress. They will have

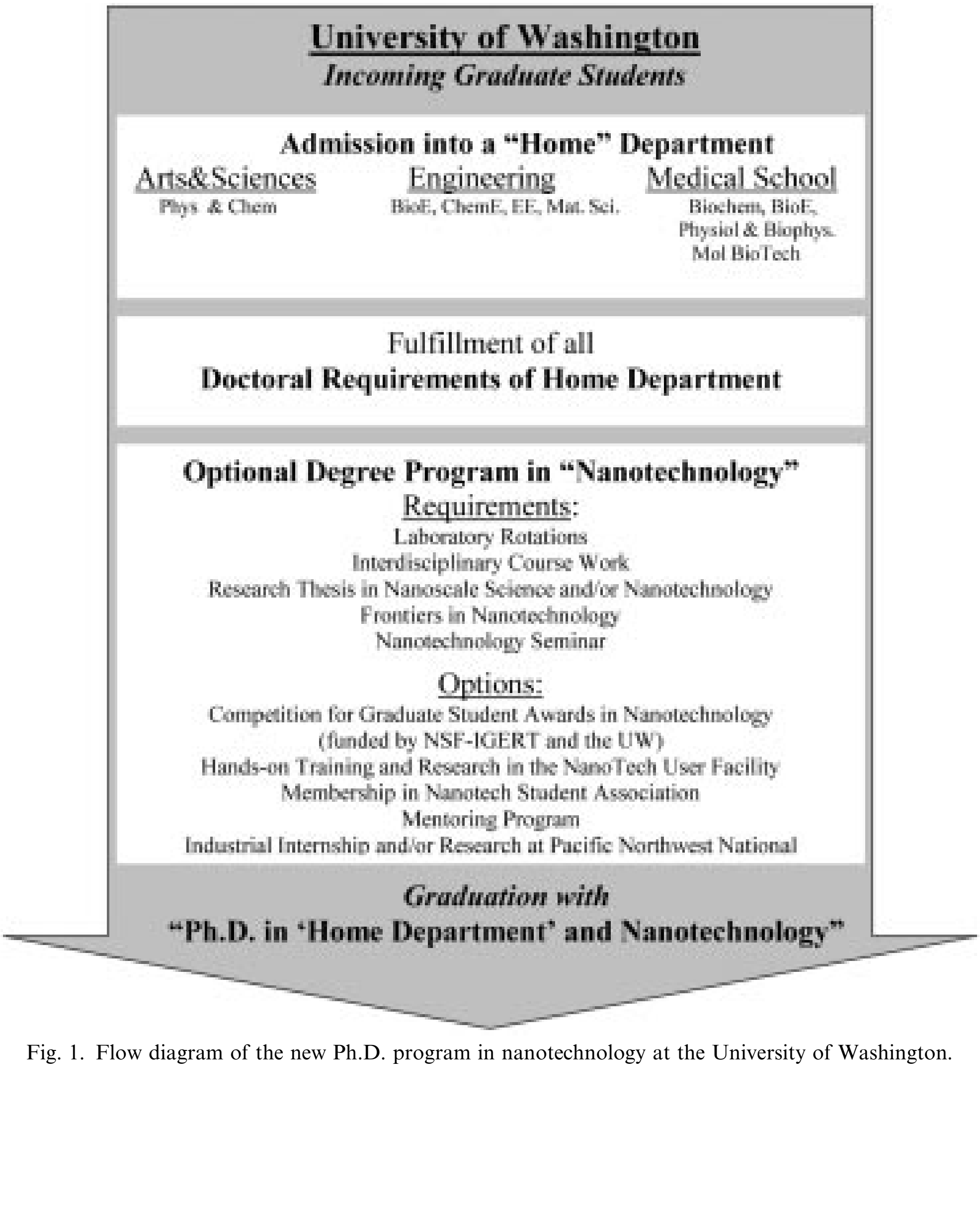

Fig. 1. Flow diagram of the new Ph.D. program in nanotechnology at the University of Washington.

the ability to effectively communicate and to lead interdisciplinary research teams in both industry and academia. The total required credits are not an unduly high burden either: many of our students pursuing interdisciplinary research projects already choose to take this much (or even more) extra course load. The new degree possibilities will allow formal recognition of their efforts: it will identify them as having this additional knowledge and experience.

STRUCTURE OF THE NANOTECHNOLOGY PH.D. PROGRAM

The flowchart in Fig. 1 outlines the new graduate educational program in nanotechnology. The participating units include the Departments of Physics, Chemistry, Bioengineering, Chemical Engineering, Electrical Engineering, Materials Science and Engineering, Biochemistry, Physiology and Biophysics and Genome Sciences from the Colleges Arts and Sciences, Engineering and the School of Medicine, respectively. Successful completion will lead to a Ph.D. combining a concurrent degree in Science, Engineering, or Medicine with Nanotechnology. In a new field, it is critical to ensure a student's viability upon completing the program: brand-new degrees are met with incomprehension, or active distrust, in both academia and industry. The field is too young to develop a standalone 'Nanotechnology' Ph.D. Therefore, as a realistic next step in the field's evolution, our graduate students can select the 'Option in Nanotechnology' after being admitted to a participating 'home' department. This option combines doctoral requirements in a department with additional (nanotech-specific) requirements defined by a steering committee. This option will be available to all graduate students who fulfill both departmental and the nanotech requirements leading, for example, to a Ph.D. in 'Chemistry and Nanotechnology' or 'Bioengineering and Nanotechnology'. A joint degree between an established discipline and nanotechnology highlights the accomplishments of graduating students who have received an interdisciplinary, cutting-edge training.

To truly innovate, and to integrate graduate student education across department lines, we will set these core Ph.D. requirements

- *Laboratory rotations.* The best exposure to another discipline, its language and thinking is obtained through hands-on research. Therefore, every student must complete at least two one-quarter laboratory rotations (3 credits/rotation), one in the home department, the second in a different department. The student's home-department major professor will usually provide the 'home' rotation: a different faculty member must guide the non-home rotation. Rotations will ensure students get early exposure to different research environments, and become familiar with a wide variety of instrumentation, technology, problems, techniques, and cultures. 'Hard core scientists' are brought together with engineers and physicians.
- *New course on 'Frontiers in Nanotechnology'.* This three-credit course which is co-lectured by nanotech faculty introduces nanotechnology students to the frontiers of nanoscale science and nanotechnology. The course covers topics including nanopatterning, nanofabrication, nanoelectronics and photonics, nanoparticles and composite materials, nanomechanics, bioanalytical nano-tools, nanoscale drug delivery systems and biological nanosystems). It also serves as our major platform for recruiting first-year graduate students into our individual labs. Since graduate students from various departments participate, this course helps bring a more interdisciplinary student population into individual research groups.
- *Other course requirements.* To ensure that our nanotech students get both an interdisciplinary classroom education and a cross-disciplinary research experience, each must enroll in at least three courses (9 credits) relevant to nanotechnology. Two must be outside the home department. The student can choose from several courses within each of the following five 'topical clusters': (a) 'nanoengineered particles and materials', (b) 'microfabrication and nanofabrication', (c) 'analytical tools to probe nanostructures', (d) 'nano-biology', and (e) 'nanotech applications'. Table 1 lists the nanotechnology-related graduate courses that are currently offered at the University of Washington.
- *Thesis research in nanoscale science and/or nanotechnology.* Graduate students qualify for the dual degree option only if their research advisor(s) and one other member of their doctoral committee are faculty members of the Center for Nanotechnology and if the thesis research is in nanoscale science and/or nanotechnology. A Standards Committee ultimately judges whether the research qualifies topically for the Nanotechnology Ph.D. option, whereas the Ph.D. exam and thesis reading committees, which are set up as usual for any Ph.D. degree in our university, decide if the research and thesis qualify in the home department. All members of a student's doctoral committee who are faculty members of the Center for Nanotechnology advise this Standards Committee on the topical suitability of the research and thesis.
- *Nanotechnology seminar.* This weekly interdepartmental seminar series focuses our intellectual interactions. It provides a forum for bringing in national and international leaders in nanoscale science and nanotechnology, and to have the nanotech graduate students present their research. Weekly attendance has increased from about 30 to often more than 100 listeners. Here faculty, students, industrial partners and visitors discuss problems, evaluate results,

Table 1. Graduate courses in nanoscale science and nanotechnology currently offered at the University of Washington, grouped by topical clusters

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

exchange ideas, get inspirations, and begin collaborations. Nanotech students must enroll for at least 4 quarters (1 credit/quarter). More details about the program can be found in the Appendix.

CHANGING THE EDUCATIONAL LANDSCAPE AT THE UW

While it is too early to assess the impact of the new Ph.D. program in nanotechnology, profound changes to the educational landscape at the UW have already occurred. From internal money of the University of Washington (the President's University Initiative Fund), the UW founded a Center for Nanotechnology in 1997, directed by Profs. Viola Vogel and Charlie Campbell. New research and educational programs are thriving since then in nanoscience and nanotechnology. While the Center for Nanotechnology counted 29 faculty members in 1997, 14 new faculty members were hired in nanoscale science and nanotechnology in the Departments of Physics (1), Chemistry (6), Chemical Engineering (2), Electrical Engineering (1), Materials Science and Engineering (3), and Bioengineering (1).

The Center for Nanotechnology currently counts more than 65 faculty from the Colleges of Arts and Sciences, Engineering, Pharmacy and School of Medicine (see www.nano.washington.edu for details on our faculty research programs in nanoscale science and technology as well as our educational programs and job information).

Getting faculty and students organized around a cross-cutting theme such as nanotechnology, the Center for Nanotechnology already has had considerable impact on graduate education. Before 1997, for instance, both students and faculty were often unaware of courses and resources outside their home departments. The UW had offered five different surface science courses, independently taught in the departments of Physics, Chemistry, Chemical Engineering, and Bioengineering. Very few of these and other courses ever had students (or faculty!) from other departments. These days, students entering the graduate programs on campus now find all the courses of relevance to nanotechnology being co-listed on our website www.nano.washington.edu.

After assessing the cumulative content of already existing courses, new courses covering nanoscale phenomena and how they can be exploited for technological advances have been developed in synchrony between the participating departments. Furthermore, the requirement that graduate students have to take courses outside their home department in order to qualify for the Ph.D. in Nanotechnology has tripled the number of students in some of our graduate courses. The questions asked from different academic perspectives have enriched the learning experiences within those classes. Students from different departments are thus meeting each other early in their careers and learn about each other's research interests. Friendships are born that facilitate future collaborations. Indeed, these students got together and formed the Nanotechnology Students Association in 2000, the first organization of its type, we believe. They hold regular meetings and organize both scientific and social get-togethers. Sarah Veach, a third year graduate student in Physics and current Vice-President of our Nanotech Student Association states:

> 'By far the most beneficial aspect to my involvement in the Nanotechnology program is that I now have an avenue to interact with other students and faculty members outside my department. My research is interdisciplinary and there are few members of my home department that I can approach to discuss problems, potential research directions, or future job opportunities. Through the nanotechnology courses, seminars, and student group I have been able to do all of these things, plus I am constantly learning about new research directions and cutting edge techniques.'

Finally, we provide graduate student support to about 25 graduate students annually (funded through a NSF Integrative Graduate Education Research Training program in Nanotechnology, and the University Initiative Fund). The graduate students are selected annually based on a competitive research proposal exploring new frontiers in nanoscale sciences and technology. Some of these early exploratory investments have already returned on the investment, leading to large new grants bringing research dollars to the University of Washington.

Another crucial component of graduate education is access to state-of-the-art equipment to probe, analyze and manipulate samples at the nanoscale. The Center for Nanotechnology has established the Nanotech User Facility, managed by Dr. Dong Qin, which offers to our students access to and training on sophisticated instrumentation for nanotechnology research (e.g. atomic force microscopy, scanning tunneling microscopy, other electron microscopies, thin film deposition equipment, microcontact printing, etc.).

In addition, we have recently established a Joint Institute for Nanoscience between UW and Pacific Northwest National Laboratories (PNNL), Richland WA, which will allow our students access to facilities at the environmental molecular science laboratory (EMSL), and will also allow them to pursue thesis research co-advised by staff scientists of a national laboratory.

Acknowledgements—We gratefully acknowledge support from the University of Washington's 'University Initiative Fund' which allowed us to establish the Center for Nanotechnology in 1997. The National Science Foundation's IGERT Program is gratefully acknowledged for support of this work. Introduction of the described Ph.D. program in Nanotechnology would not have been possible without the generous support of Marsha Landolt (Dean of the Graduate School), Denice Denton (Dean of the College of Engineering), Gary Christian (Divisional Dean of Arts and Sciences), Mary Lidstrom (Associate Dean of the College of Engineering), Daniel Dorsa (Associate Dean of the Medical School), as well as of the Chairs of the participating departments: Yongmin Kim (Bioengineering), Eric Stuve (Chemical Engineering), Howard Chizeck (Electrical Engineering), Rajendra Bordia (Materials Science & Engineering), Paul Hopkins (Chemistry), David Boulware (Physics), and Alan Weiner (Biochemistry). Major contributions to establishing this program were furthermore made by Dong Qin (Manager of the Nanotech User Facility), Jayne Muir (Program Manager of the Center for Nanotechnology), Mark Carter (Program Coordinator), Eric Shulenberger (Assistant to the Vice Provost), Lee Chetham (Executive Director of Washington Technology Center), and by our CNT faculty members and graduate students.

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Viola Vogel, founding Director of the Center for Nanotechnology, received her Ph.D. in Physics in 1987 at Frankfurt University, spent two years as a postdoctoral fellow at the University of California Berkeley, and joined the faculty of the Department for Bioengineering at the University of Washington in 1990. Her research interests are in learning how Nature engineers at the nanoscale and, inspired by Nature's principles, to delineate novel design criteria for the next generation of advanced (bio)materials and nano-engineered devices. Research topics include molecular assembly processes, motor proteins, single molecule mechanics, optical spectroscopy, biomineralization, and cell/surface interactions.

She received the Otto-Hahn Medal from the Max-Planck Society and the 'First Award' from the NIH, and served on Clinton's Presidential Committee of Advisors in Science and Technology Panel in preparation of the 'National Nanotechnology Initiative'.

Charles T. Campbell is Professor of Chemistry and Co-director of the Center for Nanotechnology at the University of Washington. He received his BS (Chemical Engineering, 1975) and Ph.D. (Physical Chemistry, 1979) at the University of Texas, Austin. He applies and develops experimental surface science techniques to study thin films, catalysis, biosensors, and materials chemistry (www.cpac.washington.edu/~campbell/index.html). He won the ACS Award for Colloid / Surface Chemistry, the John Yarwood Memorial Award, and a Dreyfus Award. He has served as Chairman of the Colloid Division of the American Chemical Society. He is on the editorial board of the Journal of Catalysis and the Journal of Chemical Physics, and is chief editor of Surface Science.

APPENDIX

Formal procedure for granting the Ph.D. in Nanotechnology

Above, we presented a broad overview of this Nanotechnology Ph.D. program. In the sections below, we outline some of the administrative details of this new Nanotechnology Ph.D. and its logistics. This formal procedure upon which a Ph. D in Nanotechnology will be granted had to be approved by the chairs of the nine participating departments.

The typical timeline for a nanotechnology (NT) Ph.D. student's progress is as follows

- Application and admission to Ph.D. program of a participating home department.
- Application for the Nanotechnology Ph.D. option program to the Center for Nanotechnology (CNT), and acceptance.
- Selection of Ph.D. supervisory committee and program development. (Advisor and at least one other committee member must be a CNT faculty member.)
- Completion of all requirements of home department needed for the Ph.D. Candidacy (i.e. General) Exam.
- Completion of NT-specific requirements (possibly simultaneous with above step).
- Presenting the proposed thesis topic for certification as 'NT-qualified' preferentially before the Ph.D. Candidacy (i.e. General) Exam as further outlined in below,
- Passing the Ph.D. Candidacy (i.e. General) Exam . Giving a copy of signed warrant, proving pass to NT-Ph.D. program manager for file.
- Completion of lab rotation requirement (possibly done wholly or partially before the Ph.D. Candidacy (i.e. General) Exam)
- Dissertation (thesis) research and writing,
- Confirming the dissertation (thesis) to be 'NT-qualified'.
- Passing final Ph.D. exam. Giving a copy of signed warrant, proving pass to NT-Ph.D. program manager for file.
- The degree will read: 'Ph.D. in [Home Department] and Nanotechnology'.

Details of requirements for NT Ph.D.

The course requirements are intended to give the student

(a) a solid foundation in selected areas within nanotechnology;
(b) a broad-based but less in-depth overview of the entire arena of nanotechnology;
(c) the solid base in the home department field expected of someone with that Ph.D. degree.

Ideally, the student will learn through these usable skills in selected areas of nanotechnology, and gain enough of a broad view of the rest of nanotechnology to know what is experimentally or theoretically possible there, and to know where to go to learn more about those other areas of nanotechnology if needed. Each NT student must:

1. Complete the home department's course requirements and other requirements for the Ph.D. Candidacy (i.e. General) Exam, and
2. Complete the new 'Frontiers in Nanotechnology' course (3 credits) with a grade of at least 3.3 or CR. This course introduces students to the frontiers of nanoscale science and nanotechnology. It is a regular course taught jointly by nanotech faculty. The course both introduces students to the thrust areas (nanopatterning, nanoparticles and composites, nanomechanics, bio-analytical nano-tools, and nanoscale drug delivery systems), and serves as a major platform for recruiting first-year graduate students into nanotechnology-related Ph.D. research. Two CNT faculty (from two colleges)

organized and co-teach this course. Other CNT faculty discuss their research fields, as guest lecturers. Since graduate students from various departments participate, this course helps bring a more interdisciplinary student population into individual research groups. This course can also serve toward required course credits for the home department, if allowed by the standard rules of the home department.

3. Complete at least 9 graded course credits relevant to NT with a minimum GPA of at least 3.5. Six (6) of these credits must be outside the home department. The student can choose from several courses within each of these 'topical clusters': (a) 'nano-engineered particles and materials', (b) 'microfabrication and nano-fabrication', (c) 'analytical tools to probe nanostructures', (d) 'nano-biology', and (e) 'nanotech applications'. A detailed list of existing appropriate (i.e., 'NT-relevant') courses is given in our web page (http://www.nano.washington.edu/education/programs.asp), where it is updated periodically. This web page also lists in more detail the requirements for the Nanotechnology Ph.D. program. These courses can also serve toward required course credits for the home department, if allowed by the standard rules of the home department. Note that some of the courses on this list may only be offered every few (or several) years and some may be discontinued eventually, at the desire of the department, which offers the course. A mechanism for adding courses to this list is also in place.
4. Students must also take at least four quarters (at one credit each) of the 'Nanotechnology Seminar' (a weekly interdepartmental seminar course (listed as Chemistry 560A and Bioengineering 599) that focuses on intellectual interactions of the UW NT community, allows NT students to present their own research, and provides a forum for bringing in national and international leaders in nanoscale science and nanotechnology). (See http://www.nano.washington.edu) for a list of recent speakers.) This course can also serve toward required course credits for the home department, if allowed by the standard rules of the home department.

The Ph.D. Candidacy (i.e. General) Exam is that required in the student's home department. However, the research advisor and at least one member of the student's committee must be CNT faculty. (See www.nano.washington.edu for an updated list of CNT faculty.) The student also must present his/her proposed research to the Nanotechnology Standards Committee (NT-Standards Committee or NTSC) for approval as being of appropriate content for a Nanotechnology Ph.D. For this purpose, the student and research advisor(s) are expected to justify why the research topic qualifies as being of appropriate content for the Nanotechnology Ph.D. option.

Thesis research, writing and progress evaluation: these will be monitored and facilitated by the student's Ph.D. Supervisory Committee. That committee should include the student's chief research advisor(s), who must be CNT faculty, and one additional CNT faculty, who help guide the student so that the thesis research continues to qualify for the NT Ph.D. option.

Final Ph.D. Exam: will be according to the exam requirements of the student's home department. The advisor as well as one member of the reading committee has to be members of the Center for Nanotechnology. At the time that the student's Reading Committee signs the Final Exam Request Form (i.e., after they have seen a full thesis draft, at least three weeks prior the Final Exam date), the student submits a 1- or 2-page statement (assigned by his/her Ph.D. advisor) to the Chair of the NT-Standards Committee recommending that the thesis be approved, summarizing the dissertation content with respect to nanotechnology, and outlining whether the objectives defined in the Ph.D. Candidacy (i.e., General) Exam have been met, or how and why they have been changed. (The student normally writes the first draft of this and the Ph.D. advisor then edits it.) The second CNT faculty member on the Reading Committee sends an independent note to the Chair of the NT-Standards Committee, again three weeks prior the dissertation defense (i.e., Final Exam), confirming that the content of the thesis is of appropriate content for a Nanotechnology Ph.D.

Summary of Nanotechnology-Specific Ph.D. requirements: In addition to the home department's normal requirements for the Ph.D., every NT student must do the following before the Ph.D. Candidacy (i.e., General) Exam

1. Fulfill NT-specific course distribution requirements (9 graded credits of NT-relevant graded electives, 3 credits of 'Frontiers in Nanotechnology', 4 credits of Nanotechnology seminar)
2. Fulfill all those course requirements and other requirements within the home department, which are required before the Ph.D. Candidacy (i.e., General) Exam.
3. Have the proposed Ph.D. research topic approved by the Standards Committee as having a sufficient nanotechnology component to qualify for the NT-Ph.D. (This may also be done shortly after the Ph.D. Candidacy (i.e., General) Exam).

Before the Ph.D. Final Exam, the student must

- Work for the equivalent of at least one quarter in each of two NT faculty laboratories, in two different departments (or do the optional external internship) and have this approved by the Standards Committee as fulfilling the 'lab rotation' requirement.
- Have the Ph.D. dissertation research topic approved by the Standards Committee as having a nanotechnology component that qualifies for the NT-Ph.D.

Administrative issues: Example positions, committees and administrative details that must be in place for this program to function include

1. *Director and steering committee.* We have a Ph.D. program director (appointed by the Dean of the Graduate School, preferably also the CNT director, currently Prof. Viola Vogel), a co-director (appointed by the Dean of the Graduate School, preferably the CNT co-director, currently Prof. Charles Campbell) and a Program Steering Committee ('PSC'). The PSC is chaired by the program director and includes a faculty member from each NT-Ph.D.-participating department, appointed by the departmental chair. The steering committee will meet as needed, but at least quarterly, to review and set program requirements, procedures, and direction. The committee members will be re-appointed every three years or as necessary due to retirement and other reasons. The PSC will decide if departments should be admitted to the NT-Ph.D. Program as a participating department (upon petition by that department). The PSC will decide if courses should be added to the list in Appendix A. Departments may petition the committee to have one or more of their courses added.
2. *Interdepartmental coordination.* Each participating department will appoint ONE person (with an alternate) to be departmental point of contact with the NT-Ph.D. program. Initially, this will be the Departmental Chairperson: we expect and prefer that this 'point' person be the Steering Committee member from that department. This point person should be prepared to answer questions from students and faculty of that department concerning this program, or know where to direct them if unsure of answer.
3. *Nanotechnology Standards Committee (NTSC).* This committee consists of five members from different participating departments, including its Chair, who will all be appointed by the Director with concurrence from the Co-Director, normally from the members of the Steering Committee. This committee must approve the student's research topic as being 'nanotechnology relevant' at both the proposal stage (i.e., at the time of the Ph.D. Candidacy (i.e., General) Exam) and at the final stage (i.e., based on the dissertation content). This committee also must approve the student's request for Lab Rotation equivalency. The Chair and committee members will be re-appointed every two years or as necessary.For policy-level matters, the primary contact for the representatives to the PSC and NTSC will be with the Director.
4. *Staff for advising and records keeping.* For day-to-day operational details such as class listings and scheduling, obtaining departmental course-codes for new offerings, advertising, scheduling of visiting lecturers and the like, the committee members, departmental representatives and students will work through the NT-Ph.D. Program Manager, a full-time position. This Program Manager will help advise students, help them with application forms and procedures, and keep their records. We have devised a simple tracking system for monitoring all NT-Ph.D. students' progress.