

Graduate Studies Handbook

Department of Biomedical Engineering

School of Engineering & Applied Sciences

University of Rochester

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I. PhD Program

A. Program objective

Biomedical Engineers use engineering to solve problems in biology or medicine with the goal of improving human health. With guidance from a research mentor, classroom instructors, and other faculty advisors, each PhD student will help define a domain of biomedical engineering and become one of the world's experts in that domain. It is the expectation of the faculty that at the time of a thesis defense, each student will demonstrate the ability to identify problems in biology and/or medicine, to devise and execute unique solutions, and to explain both the problem and solution in the clearest terms. It is also our expectation that graduates of the program will enjoy careers in academia or industry marked by professionalism, leadership, and many notable contributions to their field.

B. Curricular overview

The curricular component of the PhD program is designed to span two years with a transition from more general coursework in the first year to thesis-specific courses in the second year. While students entering the PhD program will have identified a general area of interest, each will be given an opportunity to explore the range of opportunities at Rochester before committing to a research laboratory at the end of the second semester of study. A faculty seminar and a laboratory rotations course, which together span both semesters of the first year, are important ways for students to conduct this exploration. Additionally, a common first semester course in *Analytic Foundations of BME* teaches broadly useful topics in applied math by illustrating applications to active research areas within the department.

Because it is the ability to apply engineering and physics principles to topics in biology and medicine that defines the biomedical engineer, the PhD program requires that students take at least two courses that provide in-depth examples of such application. These courses termed *BME Intensives* clearly integrate engineering with biology/medicine. *A BME Intensive is a specialized graduate course in which students apply the principles of engineering, physics or advanced mathematics to solve problems in biology or medicine.* This group includes 4 credit BME courses and a small menu of 2 credit courses. These courses will be on specialized topics, but may be chosen for exploration or as a part of the preparation for thesis research. To ensure the depth of training required for problem solving in doctoral research, the program requires that students choose several relevant courses in both biology and engineering.

The curricular preparation for research concludes with a course in proposal writing taken at the end of the second year of study. In this course, the student consults with his/her thesis advisor and works with the course instructor to write a draft proposal for the doctoral research. An updated version of this proposal will be presented as part of the official PhD qualifying exam in the fall of the same calendar year (see below).

The following summarizes the curricular requirements for the PhD degree. 90 total credits are required for graduation but most will be taken as research credits under BME595.

BME core

BME 502: *Foundations of BME* (4 credits)

8 credits of *BME Intensives* (list below)

BME 589: *Proposals writing* (2 credits)

BME593: *Lab Rotations* (2 credits)

- BME 453 Advanced Biomedical Ultrasound
- BME 454 Principles of Magnetic Resonance Imaging
- BME 460 Biological Systems Fundamentals
- BME 462 Cell and Tissue Engineering
- BME 466 Microhydrodynamics
- BME 467 Models & Simulations in BME Systems (3 cr)
- BME 474 Biomedical Sensors, Circuits & Interfacing
- BME 470 Biomedical Microscopy
- BME 483 Biosolids
- BME 485 Membrane Mechanics (2 cr)
- BME 513 MR Imaging: Spins to Brains (3 cr)
- BME 515 Neural Control of Movement (2 cr)
- BCS 448 Principles of Eye Design
- BCS 521 Audition (3 cr)

A BME Intensive is a specialized graduate course in which students apply the principles of engineering, physics or advanced mathematics to solve problems in biology or medicine.

BME502: Analytic Foundations in Biomedical Engineering (4 Credits; fall semester 1st term)

Biomedical engineering occupies a unique niche at the interface between the engineering and biomedical sciences. As such, BME practitioners must have both the intellectual and practical skills to navigate this interface successfully. The goals of this course are to introduce students to a select range of key concepts and methods from Engineering and Applied Mathematics that are common across most subdisciplines of BME and to illustrate by example how these concepts and methods can be applied directly in the study of biological systems and/or for the solving of biological problems. We expect that students completing the course will have acquired basic practical skills to develop novel analytic approaches to biological problems and will be well-prepared for subsequent coursework in their chosen discipline that will explore specific topics in greater detail (e.g. BME Intensives). The semester will be divided into four modules, each focused on a different area of Applied Mathematics and its application.

BME 593: Laboratory Rotations (2 credits; first year)

As part of the BME Core, students are required to submit a list of three desired rotations to the Graduate Coordinator. The student should contact each of the three faculty members that will supervise the rotations to set up a schedule that will complete three rotations by mid-April of the following year. To meet this schedule, the first rotation should be arranged for the second half of the fall term.

The duration of each rotation will be about six weeks. During this time students should be working on their rotation project whenever they are not in class. Thus, while activities in different laboratories are characteristically very different, it would be unlikely that a student could complete a satisfactory rotation in less than 10 hours per week. Exceptional circumstances such as summer rotations may allow students to devote more time per week for fewer weeks, but rotations should last at least three weeks. To obtain a satisfactory grade for a rotation, students must meet a performance standard that will include, among other things, proper attendance and participation

in the activities of the lab (such as journal clubs, seminars, and lab meetings), completion of experimental tasks agreed upon, the appropriate documentation and presentation of data, analyses, etc. It is not sufficient for a student to merely shadow another lab member, nor is it reasonable for faculty to expect the successful completion of a specific experimental outcome. At the completion of each rotation, both student and mentor should complete the written evaluation form (see appendix). They should meet to discuss the evaluation before the form is deposited in the student's file. The student must either prepare a written report on the project or prepare a critique of a paper that he/she previously presented to the laboratory's research group. Two credits are awarded at the end of the spring semester for three satisfactory rotations.

IND501: Ethics in Research (1 credit; fall term 1st year)

The ethical practice of research is a serious, multi-faceted topic important to all scientists. It is of particular importance in the biomedical sciences where human and animal subjects are part of the research landscape. Thus as a key part of the BME core, all students will take *IND501: Ethics and Professional Integrity* during their first semester.

BME589: Proposal Writing (2 credit; spring term 2nd year)

Writing successful research proposals is vital to the livelihood of most PhD-level scientists. The defense of a research proposal is also the basis for the qualifying exam in BME (see below). In BME589, students will be trained to write an NIH-style research proposal. The student will work with both his/her faculty advisor and the course instructor to devise a document that can be the basis for the qualifying exam and potentially the basis of an actual pre-doctoral fellowship application.

Approved Biology (11 credits)

Students are required to take at least 11 credits of biology courses from the following approved list. Students are encouraged to consider courses in both the basic and advanced listings.

Basic

*Approval of instructor required

BME 511 Cell & Molec Foundations*
IND 408 Biochemistry
IND 409 Cell Biology
IND 410 Molecular Biology
MBI 414/514 Mech of Microbial Pathogenesis
PHP 403 Cell & Molecular Physiology (3)
PHP 404 Principles of Pharmacology
PTH 507 Cancer Biology (3)
PTH 509 Pathways to Human Disease
PTH 510 Pathways to Human Disease

Advanced

ANA 531 Integrative Neuroscience (6)
BIO 419 Nuc Structure and Function
BIO 426 Developmental Biology
BIO 428 Lab in Cell and Dev Biolo
CVS 401 Cardiovascular Bio and Disease (3)
GEN 507 Advanced Genetics
GEN 508 Genes, Devel and Disease
IND 407 Cytoplasmic Structures & Functions

IND 411 Methods in Structural Biology
IND 443 Eukaryotic Genome I
IND 447 Signal Transduction
IND 520 Mitochondrial Medicine (2)
IND 525 Cell and Membrane Biophysics
MBI 473 Immunology (3)
NSC 512 Cellular Neuroscience (6)
PHP 440 Topics in Vascular Biology (2)
PTH 593 Mol. Basis of Human Disease

Approved Engineering (8 credits)

Students are required to take 8 credits of engineering courses from the following list.

CHE 411 Intro to Prob. for Chem. Engrs.
CHE 413 Molecular Self Assembly
CHE 421 Thin Film Processing
CHE 441 Adv Fluid Dynamics
CHE 447 Liquid Crystals
CHE 454 Interfacial Engineering
CHE 460 Biochem&Tech Clinic Diag
CHE 480 Chemistry of Adv. Materials
CHE 482 Processing Microelectronic
CHE 486 Polymer Science & Tech

ME 401 Methods of Applied Math
ME 402 Partial Differential Eq.
ME 406 Dynamical Systems
ME 411 Mech Properties of Polymers
ME 424 Robust Design/Quality
ME 437 Incompressible Flow
ME 440 Mechanics of Structures
ME 441 Finite Elements
ME 443 Mechanical Vibrations
ME 444 Continuum Mechanics
ME 449 Elasticity
ME 458 Nonlinear Finite Elements
ME 459 Applied Finite Elements
ME 461 Fracture and Adhesion
ME 463 Microstructures
ME 481 Mechanical Properties

OPT 411 Math/Theoretic.
OPT 421 Opt Properties of Semi-con
OPT 425 Radiation & Detectors
OPT 428 Opt. Commun. System
OPT 441 Geometrical Optics
OPT 442 Instrumental Optics

OPT 443 Opt Fabrication & Testing
OPT 444 Lens Design
OPT 452 Medical Imaging: Th.& Prac.
OPT 462 Physical Optics II
OPT 465 Laser Systems
OPT 467 Non-Linear Optics
OPT 461 Physical Optics
OPT 476 Biomedical Optics
OPT 492 Opt Interf. Coating
OPT 551 Intro to Quantum
OPT 552 Quant. Opt Electromag. Field
OPT 553 Quant. Opt Atom-Field
OPT 563 Statistical Optics
OPT 564 Electr Imaging Sys.
OPT 568 Waveguide Opto-elect.
OPT 592 Nano-Optics

ECE 401 Adv Computer Architecture
ECE 404 High Perf Microprocessor
ECE 423 Semiconductors
ECE 425 Superconductivity
ECE 431 Microwaves & Wireless
ECE 432 Acoustic Waves
ECE 435 Intro to Optoelectronics
ECE 437 Wireless Communications
ECE 440 Intro to Random Processes
ECE 444 Digital Communications
ECE 446 Digital Signal Processing
ECE 447 Digital Image Process
ECE 450 Information Theory
ECE 452 Med Imaging-Theor &Implemt
ECE 461 Dig Iteg Circuit Design
ECE 461 Dig Iteg Circuit Design Lab
ECE 462 VLSI Design Project

ECE 465 Issues in VLSI/IC Design
ECE 466 RF Integrated Circuits

ECE 441 Detection & Estimation Theory
ECE 585 Phy of Adv Opto-Electronics

Total Credits

For a doctoral degree the University requires a total of 90 credit hours. The number of course credits needed to meet the minimum BME PhD requirements is 40. The remaining 50 credits, if not earned through additional coursework, will be earned as research credits under *BME595: PhD Research*.

D. Other Requirements

Teaching Assistantship

Each student will be required to be a teaching assistant for at least two semesters. Students are welcome to request specific teaching assignments and efforts are made to accommodate such requests. Assignments will be made by the Graduate Director and approved by the Graduate Committee.

Public Presentation

The clear communication of a research effort is a vital skill for any scientist. The research effort itself benefits from the preparation, delivery, and discussion associated with a presentation, *especially* if the work is not yet a completed story. For these reasons the program requires a minimum of four presentations throughout a student's tenure. The first presentation satisfying the requirement will occur at the end of the first year as part of the rotations course. To complete this course, all first year students will make presentations on one or more of their rotation projects in a public session. At least one more departmental presentation must be made before the thesis defense, and this will typically be satisfied by the qualifying exam presentation. The remaining presentations can be departmental seminars or presentations at national meetings. Only one poster presentation at a national meeting can be applied toward the presentation requirement.

E. Advising and Committees

Graduate Committee

The Graduate Committee is responsible for administering the PhD program. This committee sets program requirements and policies and monitors students to determine their status within the program. The Graduate Committee administers the first year exam and approves thesis advisory committees (below) and assigns chairs for qualifying exams. The committee also considers petitions for graduate course transfers and exemptions to requirements or policies.

Academic Advisor

First year students will be assigned faculty academic advisors with research interests similar to their own. These advisors are responsible for helping students plan courses

during the first two semesters of study, and students will need an advisor's signatures on registration forms in order to register for classes.

Thesis advisor

Any member of the BME Graduate Faculty may serve as a PhD thesis advisor. All primary members of the department are members of the Graduate Faculty. Many, but not all secondary appointments in the department are members of the Graduate Faculty. Graduate Faculty Members are listed on the program web pages www.urmc.rochester.edu/bme/people/faculty/.

Preliminary Exam Committee

By April 15th of the second term of study first year students should be nearing completion of their rotations. At this time, students will be asked to select a thesis advisor. The choice of the thesis laboratory will be used to design a preliminary exam and an exam committee for each student. The preliminary exam committee will include the likely mentor, one member of the Graduate Committee, and a second member of the thesis advisor's track. The exam committee will be revealed to the student at least one week in advance of the exam. The exam committee will review the student's curricular strategy as a formal step in the exam process. Details on the preliminary exam procedure are below. Upon successful completion of the exam students are expected to quickly begin work in their laboratory of choice. The student's thesis advisor will also become his/her academic advisor for the second year of study and beyond.

Research Advisory Committee

After beginning work together, a student and his/her thesis advisor must define the direction of the doctoral research and identify members of the UR faculty that will comprise the thesis advisory committee. The thesis advisory committee performs several functions. It provides advisory input during the development of the thesis research project with respect to scientific merit, techniques and methodology, relevant literature, etc. It serves as the Qualifying Exam Committee (see below). Finally, it, along with a representative appointed by the University Dean of Graduate Studies as Chair, is the examining committee for the thesis defense.

The thesis advisory committee must consist of the research advisor, at least two other members from the Graduate Faculty in Biomedical Engineering and one faculty member who is not a member of the Graduate Faculty. At least one member of the advisory committee is expected to have trained a graduate student through completion of a doctoral degree. Additional committee members may be included from either within or outside the University if it is considered useful or necessary. Thus, the minimum size of the committee will be four members, but five (or more) is quite possible. In the case of co-advisors, a minimum of five members is required. Any exceptions to this procedure will have to be approved by the Associate Dean for Graduate Studies of The College and the University

Dean of Graduate Studies. By January of the second year, the student must submit a list of suggested committee members to the Graduate Administrator for review by the Graduate Committee.

Once the advisory committee is formed during the spring of the second year, the student should quickly hold an informal meeting with the committee. The student and the committee should discuss the student's emerging research proposal in the concurrent proposals class, the courses taken by the student in preparation for the research topic, and the appropriateness of the committee members to serve as advisors. It is strongly encouraged that students set a fall date for the Qualifying Exam at this meeting.

Once a student passes the Qualifying Exam, he/she is required to inform their advisory committee of progress twice a year. One progress report must include (and may be limited to) an oral presentation with all committee members present. A second progress report must include (and may be limited to) a written document that explains research activities and progress. In both instances the committee and the student must complete the Graduate Student Research Review form (appendix) and submit it to the Program Office. If two progress reports are not on file each academic year (by June 1), stipend funding may be terminated.

F. Preliminary (first year) exam

Objective

The objectives of the preliminary exam are to:

- A. Clearly identify students who are not likely to make successful biomedical engineering graduate students
- B. Ensure that students are executing a curricular plan that will provide engineering and biological depth and the biological and engineering breadth appropriate to their chosen field of research

Subject and Procedure

The subject of the preliminary exam is a recent article from the literature. In April of each year. The Graduate Committee will organize exam committees for each student. Each committee will assemble a collection of papers that align with the background and interests of the student. First year graduate students will meet with the Graduate Program Director shortly after finals week in May. At this meeting the Director will review the instructions for completing the exam and explain the expectations for passing the exam. Each student will be presented with his/her collection of papers and must select from this collection the paper that will be the subject of the exam. Exam committees will be quickly notified of the papers selected.

After selecting a paper students will be given 14 days to prepare a report. Reports are to be no more than 20 double spaced pages, 12pt font (or an alternative legible format of

equivalent length). Figures and legends should be embedded within the text, but the references can be listed after the text. The report should begin with an executive summary. The report must include a critical evaluation of the paper and an example of the student's ability to apply quantitative engineering approaches to medicine/biology.

The critical analysis should address: 1) the significance of the study in the context of human health, 2) the findings of previous studies that address similar questions, 3) the quality of the work, data, and/or model(s), and 4) the strength of the conclusions.

The engineering analysis can be used to evaluate the paper, to provide a clearer explanation of complex mathematical ideas within the paper, and/or to illustrate an extension of the paper for future research.

Examples of how engineering analysis might be used for the exam:

- a) A student develops a simplified version of a simulation included in the paper and uses it to demonstrate how different (but reasonable) parameter choices lead to conclusions very different than the authors'
- b) By consulting supporting literature a student is able to clearly derive a complex set of expressions used (but not derived) in the paper. The student concludes that the analysis is fundamentally correct. She now better understands the assumptions inherent in the work and can explain why the assumptions are reasonable given the experimental conditions used.
- c) A student develops an idea for extending the work in the paper using a different device than that used by the authors. The student presents a "back-of-the-envelope" style analysis of his device that clearly identifies the design parameters for the new device and how they might be adjusted to answer the biological question

Students are cautioned that their prepared materials must obviously include both an engineering analysis and a critique. A student failing to meet this requirement will automatically fail the exam.

Within a week following submission of the document, students will have an oral exam before their Committee. **STUDENTS MUST RECEIVE THE PROGRAM OF STUDY FORM FROM THE GRADUATE COORDINATOR AND RETURN THE FORM WITH THE REPORT.** During this time students are to prepare a ~20 minute oral presentation on the paper and their report. The presentation may include extensions or corrections to the written analysis. Students are required to add to the end of the presentation a single slide listing their course choices and the rationale behind these choices. This slide and any discussions that follow will not be included in the 20 minute time limit for the student presentation. Students are advised to review all graduate and undergraduate materials that might be reasonably connected to the paper through questioning. The paper is used as a starting point for questioning, but the student's understanding of fundamental engineering principles and biology will be tested during the oral portion of the exam.

Basis for Evaluation

The examining committee will question the student for a minimum of 1 hour after the student's presentation. The committee will evaluate the student based on four equally weighted criteria:

- A) Is the student an independent (*i.e. critical*) thinker?
- B) Is the student capable of communicating in a professional, clear, and scholarly manner?
- C) Is the student clearly able to apply principles of engineering/physics to biology/medicine?
- D) Is the student able to apply knowledge of biology/physiology to solve a problem in biomedical engineering?

At the close of questioning the committee will meet without the student to determine a final score. The student cannot pass the exam if the committee concludes that effectively the student included no engineering analysis or critique in the prepared portions. The examination panel will also determine if the student is executing a curricular plan that will provide engineering and biological depth and breadth appropriate to their chosen field of research. A member of the exam committee will meet alone with the student to explain the results. Students must be informed that they will not officially pass or fail the exam until faculty discuss their exam and their complete academic record at the next faculty meeting.

G. Qualifying Examination

Objective and basis for evaluation

The goal of the PhD qualifying exam is to determine whether the PhD student is prepared to conduct a high-quality inquiry in an important area of medical or biological science. The basis of the PhD qualifying exam in BME is a research proposal that is both *written and defended by the student*. Through written and oral presentations, and through oral discussion, the student must convince the exam committee that:

- 1) The proposed research addresses an unsolved, scientifically important problem
- 2) The proposal contains an approach that is well-reasoned, well-controlled, innovative, and optimized. In other words, the plan is likely to be met with some success.
- 3) That the student has the ability to successfully complete the work using the resources available to them.

Format of proposal

Students are instructed to use a standard NIH-style format for their proposal. Details of the format are provided below. Include a cover, abstract, table of

contents, references, and appendices if needed. These pages do not count against a 15 page limit for the body of the proposal.

Font

Use an *Arial, Times New Roman, or Helvetica* typeface and a font size of 11 points or larger. (A Symbol font may be used to insert Greek letters or special characters; the font size requirement still applies.) Type density, including characters and spaces, must be no more than 15 characters per inch. Type may be no more than six lines per inch. □Print must be clear and legible.

Page Margins

Use *standard size (8 1/2" x 11")* sheets of paper. Use at least 3/4 inch margins (top, bottom, left, and right) for all pages, including continuation pages.

Paging

The application must be single-sided and single-spaced. Consecutively number pages throughout the application. Do not use suffixes (e.g., 5a, 5b). Do not include unnumbered pages.

Figures, Graphs, Diagrams, Charts, Tables, Figure Legends, and Footnotes

A smaller type size may be used but it must be in black ink, readily legible, and follow the font typeface requirement. Embed key figures in the document and place additional figures in appendices.

Proposal Sections

- A. **Specific Aims:** State concisely and realistically what the research described in the proposal is intended to accomplish and/or what hypothesis is to be tested. Target one page.
- B. **Significance:** Briefly sketch the background to the proposal and critically evaluate existing knowledge. State concisely the importance of the research described in the proposal by relating the specific aims to longer term objectives. Do not exceed five pages.
- C. **Preliminary Studies:** Students are not expected to have a large amount of data accumulated at the time of the Qualifying Examination. This section should summarize what work has been done by the student and by other laboratories to indicate that the proposal is realistic and significant in scope. Do not exceed four pages. Graphs, diagrams, tables, and charts relevant to this section can be included as "Appendix" material.
- D. **Proposed Experiments:** Discuss in detail the experimental design and the procedures to be used to accomplish the specific aims of the work described in the proposal. Describe the protocols to be used and a tentative timetable for the investigation. Include the means by which the data will be analyzed and interpreted. Describe new methodology and its advantage over existing methodology. Discuss

the potential difficulties and limitations of the proposed procedures and alternative approaches to achieve the aims. Include information about species of animals to be used. There is no page limitation for this section but make every attempt to be concise.

- E. References: Use a standard journal format that includes names of authors and full title.
- F. Appendix: Graphs, diagrams, tables, and charts supporting the proposal should be included in this section. Note that these may not be read by the committee and therefore should only contain supplemental – not essential – data. One or two key publications may also be included.

EXAM COMMITTEE

The exam committee will be the members of the student's thesis advisory committee, with the exception of the student's thesis advisor. The exam chair is selected by the Graduate Committee and will vote and question in place of the advisor.

Timing

The Qualifying Examination should be taken before the end of the first semester of the third year. Waiting longer only increases the expectations of the advisory committee on exam day. Students must have completed a minimum of 24 hours of course work credit, as outlined above, at the time of the Qualifying Exam. The completed Ph.D. thesis research proposal must be submitted to each member of the thesis advisory committee and to the Program Office at least two weeks before the day of the examination. Students should inform the Graduate Program Administrator at least one month in advance of the exam date as the Graduate Committee must select the exam chair and the exam must be formally approved by the Dean of Graduate Studies in the College.

Procedure

Students must hold a public oral presentation prior to the exam. The presentation does not need to coincide with a departmental seminar series, it simply must be advertised to the department as an open session. The seminar should not exceed 50 minutes in duration. Following the presentation, the student and committee will meet for a closed examination. A typical examination will take between two and three hours. At the close of the exam the committee chair will meet alone with the student to explain the committee's findings.

F. Thesis Preparation and Registration

A booklet entitled "The Preparation of Doctoral Theses" is available in the BME Office. It is the responsibility of the student to see that style, format, margins, paper, binding, etc. are in accordance with University regulations. The student should be aware that the Dean of Graduate Studies has a deadline each year by which time a thesis must be registered in order to allow graduation at the next Commencement. This date is typically the first week in April although students should notify the Graduate Studies Office by February 1 of their intent to register a thesis before the deadline. It will usually take at least three months to prepare the thesis after all experimental work is complete and the most common mistake lies in not allowing adequate time for preparation of illustrations, typing, review by the advisor and thesis advisory committee and for registration in the Graduate Dean's Office.

Registration with the office of the Associate Dean of Graduate Studies must take place at least 20 full working days before the final exam. (Registration deadlines vary. Please check in the Program Office for a schedule of dates for the academic year. Final exams may not be scheduled during specific periods, e.g., August through mid-September.) At least one week before that time, the student should bring to the Program Office:

1. A list of the members of the thesis advisory committee.
2. Date, time and place for the proposed final exam.
3. One copy of the thesis title page.
4. One copy of the thesis abstract.

The Graduate Coordinator will provide the student with the additional required forms. The student will also be given termination forms at the time of the exam to complete before departure. The student then takes the completed forms to the Office of the Associate Dean for Graduate Studies. At registration, the student must bring to the office of the Dean of Graduate Studies a copy of the thesis to be given to the Chairperson of the Examining committee. All other committee members should also receive a copy of the thesis at this time.

Please see the "Regulations and University Policies concerning Graduate Studies" in the Graduate Bulletin for details.

G. Final Examination and Termination

Before the final exam, the student's advisor will receive confirmation of the scheduling of the exam and name of the Chairperson of the Examining Committee appointed as the representative of the Vice-Provost of Research and Graduate Affairs.

The format of the Final Examination for the Ph.D. is as follows. The first hour of the exam is an open seminar to the public. The student's presentation should last 45 minutes and 10 minutes are allowed at the conclusion for questions from the audience. The student and the Examining Committee will then adjourn to a private session where the second part of the exam will be conducted. Using oral interrogation, the committee will scrutinize the student's comprehension, execution, description and interpretation of the research described in the thesis.

After successful completion of the Final Examination and after making any required corrections in the thesis, the student must submit two corrected unbound copies of the thesis to the office of the Associate Dean. This copy must be unbound in a manila envelope with the student's name and department marked plainly on the outside. In addition, one unbound copy must be submitted to the Department Office.

H. Summary of Student Responsibilities

At the end of the first academic year

- Choose a research advisor (April 15)
- Complete rotation sequence and make department presentation
- Complete preliminary examination (June)
- Begin Ph.D. thesis research (Mid-June)

Second Year

- No later than January, submit a proposed Advisory Committee to the Program Office
- Complete course work.
- Meet with Research Advisory Committee by June 1
- Organize thesis proposal
- Complete TA requirements

Third Year, Fall Semester

- Notify Graduate Administrator of planned date for proposal more than one month ahead of time so Chair can be selected
- Submit final copy of research proposal to Program Office and Advisory Committee Members (two weeks before exam).
- Complete qualifying examination by December 1

Each year after – Two progress reports are mandatory one oral and one written.

Note: the expectation of the program is that students should not take more than six years to successfully complete the Ph.D. University Regulation require that students exceeding a 7 year stay receive approval for an extension both from the department (Graduate Committee) and the Associate Dean of Graduate Studies.

II. MS Programs

A. Program Objective

The department offers two types of Master of Science degrees. The first is the Plan A or 'thesis' masters and the second is the Plan B or 'coursework' masters. The primary goal of the Plan A masters is for a student to successfully execute and communicate an in-depth research project. In Plan A, courses are taken both in support of the research project and to broaden the student's educational experience. The primary goal of the Plan B masters is for a student to develop and demonstrate their advanced understanding of biomedical engineering principles. Courses are selected to provide depth in an area of the student's interest and to develop an understanding of the breadth of applications in biomedical engineering.

B. Curricular Requirements

Both degrees require 30 credits with more than 12 credits taken at the graduate level (these courses are numbered 400 and above). Specific credit requirements for each degree are summarized in the following table.

<i>Plan A</i>	<i>Plan B</i>
<i>BME502: Analytic Foundations (4 credits)</i>	<i>BME502: Analytic Foundations (4 credits)</i>
<i>14 credits from:</i>	<i>14 credits from:</i>
BME Intensives (4 credits minimum)	BME Intensives (4 credits minimum)
Approved Engineering (4 credits minimum)	Approved Engineering (4 credits minimum)
Approved Biology (4 credits minimum)	Approved Biology (4 credits)
<i>IND501: Ethics in Research (one credit)</i>	
<i>6-11 research credits</i>	<i>6-11 additional credits (6 research credits maximum)</i>
30 credits total with 24 or more credits > 400 level	30 credits total with 24 or more credits > 400 level

Specific course descriptions, and lists of courses satisfying the *BME Intensives*, *Approved Engineering* and *Approved Biology* requirements are specified in the detailed description of the PhD curricular requirements (Section I-C).

C. Financial Support and Teaching Assistantship

Competitive tuition scholarships are available for both Plan A and Plan B students. Students receiving a tuition scholarship may be asked to serve as teaching assistants for 1 semester. Part-time students are not eligible for the tuition scholarship and are not required to be teaching assistants.

The department does not guarantee stipend support for any masters student, although some Plan A (and even some Plan B) students may be paid for their work in research laboratories. Federal loans are available to assist with cost-of-living expenses.

Information on graduate loans is available at the University's financial aid website: <http://www.rochester.edu/living/services/financial/financialaid/>.

D. Continuity

All MS students, including part-time students, must register each term to continue progress toward the MS degree. If students fail to enroll for any term, the College may terminate a student's status with the university. To maintain continuity, full-time Plan A students who have completed coursework should register for 0 credits of *BME899: Master's dissertation* until the thesis is complete. Part-time Plan B students who do not wish to take a course in a particular term should register for *BME895: Continuation of Master's enrollment* or for *BME985: Leave of absence* if they anticipate more than one term away from the university.

E. Duration

A full-time student should not take more than 1 year to complete all the Plan B Master's requirements. A full-time student will typically take more than one year to complete the Plan A thesis. In the first year of study, a student in Plan A should satisfy all credit requirements, become fully trained in the laboratory, and make substantial progress on the thesis project. The teaching assistantship should also be completed in this year. Typically, all efforts beyond the 1st year are devoted to the completion of the research thesis. The University has a five-year limit on the time taken to complete any Master's degree (Plan A, Plan B, full-time or part-time).

F. Advising

Plan A students should identify a thesis advisor before beginning their first term and the thesis advisor will serve as the student's academic advisor. The advisor will help the student construct a program of study appropriate to the student's interest, abilities, and the demands of the research project. All members of the BME Graduate Faculty as well as Secondary Faculty may serve as a MS thesis advisor. Graduate and Secondary Faculty are listed on the program web pages www.urmc.rochester.edu/bme/people/faculty/.

Plan A students are also required to form a thesis advisory committee. This committee must consist of 1) the thesis advisor, 2) one faculty member who is part of the BME Graduate or Secondary Faculty, and 3) one faculty member from outside the department (*i.e.* not part of the BME Graduate or Secondary Faculty). The student is required to meet with the advisory committee at least once before taking the exit exam and this meeting should take place at least four months before the exam.

Plan B students will be assigned an academic advisor before beginning their first term of study. This advisor will help the student construct a program of study and must sign registration forms each term.

G. Thesis and Exit Exams

Plan A

Plan A students are required to prepare a written thesis following the format specified for the PhD degree (see Section I-F). The thesis document must be registered with the Associate Dean for Graduate Studies, and copies must be delivered to the members of the examining committee at least two weeks prior to the oral exam. The BME Graduate Coordinator will assist the student in registering the thesis with the Associate Dean for Graduate Studies. The thesis work must be presented in a public seminar and followed by a closed session oral examination. The written document, the prepared presentation, and the oral exam will be used in evaluating the following criteria:

- A) Is the student clearly capable of executing an original study over a prolonged period?
- B) Is the student capable of presenting the rationale and results of new study in a clear manner?
- C) Did the student become thoroughly acquainted with the literature in a limited field?

Plan B

A student in Plan B must pass a comprehensive oral examination. Two formats are offered for the exam: 1) a course-based exam, or 2) a literature-based exam. The advantage of the course-based exam is that a student can schedule the exam at any time. A student wishing to participate in May commencement can schedule the exam in the final weeks of the spring term (the student will receive a firm deadline by e-mail for May commencement). The literature-based exam follows the PhD preliminary examination schedule and thus will always take place in June. A student must inform the program office of the desired exam format by March 1st (Oct 15st if a course-based exit exam is to be taken at the end of the fall term).

Course-based exam: In this exam, the student will ask two or more members of the BME faculty to serve on his/her exam committee. The proposed exam committee and the exam date should be registered with the BME office one month prior to the exam to give the graduate committee time to approve or revise the student's proposal. During the exam, the committee will question the student on topics from his/her graduate coursework. Questions should be drawn from courses satisfying the BME Intensive, Approved Biology and Approved Engineering requirements. It is reasonable for the student and committee to agree beforehand on the specific courses that will be included in the exam. The student passes the exam if he/she demonstrates mastery of the included topics.

Literature-based exam: This exam follows the PhD preliminary exam format as outlined in section I-F, except that the basis for evaluation is different. Like 1st year PhD students, MS student's taking this exam will meet with the Graduate Program Director the first Monday after finals week in May. At that time, each student will be given a collection of articles assembled for him or her by the Graduate Committee. The student will be given

until Friday to select the article that will be the basis of the exam. The student will then have two weeks to prepare a report on the paper. The MS report should begin with an executive summary and be no more than 20 double-spaced pages, 12 pt font (or an alternative legible format of equivalent length). Figures and legends should be embedded within the text. The report should demonstrate a clear understanding of the article and include all the key engineering and biology background. After turning in the report, students will have one week (two weekends) before oral exams begin. During this time students are to prepare a ~20 minute oral presentation on the paper and their report. Students are advised to review all graduate and undergraduate materials that might be reasonably connected to the paper through questioning. The Graduate Committee will assemble an exam committee consisting of three members of the Graduate/Secondary faculty including one member of the graduate committee (or a representative). This committee will evaluate the student's written report and presentation. As criteria for passing, the exam committee must decide:

- A) Is the student capable of understanding a recent journal article from a field of interest, and of clearly explaining the article in oral and written presentations?
- B) In an oral examination, is the student able to draw on graduate coursework to explain concepts contained within or peripherally related to the article?

Students who fail to satisfactorily meet either of these criteria will fail the exam.

Re-examination: Any student failing either format of the exit exam may be allowed to re-take an exam of the same format. The Exam Committee will recommend whether or not a student should be permitted to retake the exam, but the Graduate Committee will make the final decision. According to university regulations, the re-examination can happen as soon as the following semester, but not more than one year after the first exam. No student is permitted to take the exit exam a third time.

F. 3-2 Masters Program

Early admission to the masters degree is possible for exceptionally well-qualified undergraduate BME majors at the University of Rochester. Admission to the 3-2 program provides students with flexibility in scheduling courses in the senior and fifth years of study. Students must apply by April 1 of their junior year for admission to the program and should consult the BME program office for details of the application process. As part of the application students will complete a program of study that 1) completes all undergraduate requirements before the start of the spring semester of the fifth year of study, and 2) satisfies all the MS curricular requirements outlined above. A student in the 3/2 program must serve as a TA for one term.

III. MD/PhD Program

Students earning a PhD in Biomedical Engineering through the MD/PhD program will begin PhD training in the third year of graduate school after two years of medical school training. Unless explicitly stated below all requirements and definitions for the PhD in Biomedical Engineering (Section I) apply to students in the MD/PhD program.

A. Curricular requirements

Because the medical school training emphasizes biology and physiology, the BME PhD requirement for 12 credits of Approved Biology are waived. Additionally, only 4 credits of BME Intensives are required, and the preliminary exam is waived. A teaching assistantship is encouraged but not required. The BME faculty believe that experience and training in teaching is a valuable part of doctoral education for biomedical engineers, however the program does not require TA service in order to be consistent with MD/PhD requirements in other departments. At least two rotations are required by the MD/PhD program and these are typically completed before beginning the PhD training. The following summarizes the full non-research requirements for BME PhDs in the MD/PhD program:

- 12 credits of approved engineering
- *BME502: Analytic Foundations in BME* (4 credits; fall term)
- 4 credits of BME Intensives
- The proposals writing course (2 credits; spring term)
- Research ethics (1 credit; fall term)
- Three formal presentations in a public forum

A student should complete the curricular requirements in one academic year, and it is expected that 2-3 additional years will be required to complete the PhD thesis. Students must select a research advisor by the beginning of the spring term, and research should be underway by the spring term so that the proposal writing class is most effective. The qualifying exam should be taken in the fall of the second year of PhD study.

B. Clerkships

During the years of doctoral training, students will continue with clerkship activities for one afternoon each week to remain active in medical training. The clerkship time accumulates as medical school credit, and enables the student to have a free block in the last year of medical training to pursue either additional elective or further research activities.

IV. General Policy

A. University Graduate Policy

This handbook summarizes the major features and policies of the graduate program in Biomedical Engineering. The broader policies that govern BME and all graduate programs are summarized in the Graduate Bulletin (<http://www.rochester.edu/GradBulletin/>; updated every two years). Both students and advisors will need to consult both sources, though it is our intent to provide the salient features here. Policy, of course, continues to evolve in response to the changing needs of the graduate program and the students in it.

Thus, it is wise to verify any crucial decisions with the Biomedical Engineering Graduate Committee.

B. Vacation

Graduate students are entitled to two weeks of vacation each year in addition to official University Holidays. Students must inform their advisors of any absence and are expected to coordinate the timing of vacations with their advisors. Because the Department Office must submit monthly time reports on all graduate students and these are subject to close scrutiny by auditors from both the governmental accounting office and the University, all students must get approval from the Department Office for any absence of more than two weeks (10 working days). Students will not receive stipends if absent without authorization.

C. Termination without graduation

A student may be asked to leave a degree program before graduation if: 1) he/she does not pass preliminary, qualifying or final (exit) exams, if 2) the student earns a grade of C for eight credits or two or more classes, if 3) the student's advisory committee (or academic advisor for Plan B MS students) indicate that the student is failing to make satisfactory progress toward a degree over a period of at least one year, if 4) the graduate committee determines that the student has accumulated a significant record of poor performance in any number of evaluated areas including: class work, research, exams, rotations, and teaching assistantships; or if 5) the student's behavior is detrimental to the welfare of individuals, the program, or the department. Final decisions on termination are made by the Graduate Committee after a careful review of the student's record. An exception is the case of poor academic standing (case 2) which, according to University policy, is reviewed by the associate dean for graduate studies.