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 Advanced BME courses that provide in-depth examples of such application. An Advanced BME course is a specialized graduate course (>200-level) 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 can 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 from pre-approved lists.

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).

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 39 . The remaining 51 credits, if not earned through additional coursework, will be earned as research credits under BME595: PhD Research.
The following summarizes the curricular requirements for the PhD degree.

**General Requirements (4 Credits)**
- IND 501 Ethics in research (1 credit)
- Applied Statistics in the Biomedical Sciences (BST 467 – 3 credits)
  + Biostatistics Bootcamp (IND 418 – 0 credits)

**BME Core (12 Credits)**
- 8 credits of Advanced BME (list below)
- BME 589: Proposals writing (2 credits)
- BME 593: Lab Rotations (2 credits)
- BME 496: Weekly BME Seminar (0 credits)

**Advanced Requirements (23 Credits)**
- 11 credits of Approved Biology (list below)
- 8 credits of Approved Engineering (list below)
- 4 credit elective (this is free but should be relevant to a career in BME and must be approved by prelim exam committee)

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*Zero Credits BME Seminar is required attendance throughout the academic year*
Typical schedule of courses for the PhD program. Up to 16 credits are represented each term. Students will select advanced BME, engineering, biology, and elective courses to support their research interests. Students should consult the program web pages: at [http://www.bme.rochester.edu/research/](http://www.bme.rochester.edu/research/) for faculty recommendations in specific research tracks, and at [http://www.bme.rochester.edu/graduate/courses.html](http://www.bme.rochester.edu/graduate/courses.html) for Advanced BME course listings.

C. Detailed Curricular requirements:

**General Requirements (4 credits)**

- **a 1st semester course on Ethics & Professional Integrity In Research (IND 501, 1 credit)**
  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.

- **BST 467 Applied Statistics in the Biomedical Sciences (3 credits)**
  This is an introductory level biostatistics course designed for PhD students in the biomedical sciences. This course will cover the topics on probability and probability distributions, sampling distributions, statistical inferences from small and large samples, analysis of categorical data, analysis of variance, correlation and simple linear and non-linear regression analysis. All analytical topics will be illustrated using examples from biomedical sciences areas. *Concurrent registration or completion of IND 418 (0 credits) Biostatistics Bootcamp is required.*

**The BME Core (12 credits)**

- **BME 593 Laboratory Rotations (2 credits over 2 semesters)**
  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.

- **BME 589 Writing Proposals in BME (2 credits)**
  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.

- 8 credits of *Advanced BME courses* chosen from … (courses are 4 credits unless noted)
  - BME 404 Computational Methods Applied to Biological Systems
  - BME 412 Viscoelasticity in Biological Tissue
  - BME 418 Introduction to Neuroengineering
  - BME 420 Biomedical Nanotechnology (2 cr)
  - BME 428 Physiological Control Systems
  - BME 442 Microbiomechanics
  - BME 445 Biomaterials Science and Engineering
  - BME 448 Controlled Release Systems (2 cr)
  - BME 451 Biomedical Ultrasound
  - BME 452 Medical Imaging
  - BME 453 Advanced Biomedical Ultrasound
  - BME 454 Principles of Magnetic Resonance Imaging
  - BME 455 Translational Biomedical Optics
  - BME 460 Quantitative Physiology
  - BME 462 Cell and Tissue Engineering
  - BME 465 Cell Adhesion (2 cr)
  - BME 466 Bioprocess Engineering
  - BME 467 Models & Simulations of Biomedical Systems
  - BME 474 Biomedical Sensors, Circuits & Interfacing
  - BME 483 Biosolid Mechanics
  - BME 485 Cell & Membrane Mechanics (2 cr)
  - BME 486 Finite Elements
  - BME 487 Nonlinear Finite Elements Analysis
  - BME 489 Electrochemical Biosensor Design Syllabus
  - BME 513 Intro to fMRI: Imaging, Computational Analysis and Neural Representations (3 cr)
  - BME 515 Advanced Topics in Neural Control of Movement (2 cr)
  - BME 592 Spec Topics: Mechanobiology
  - BCS 521 Audition (3 cr)
  - OPT 448 Vision and the Eye
**Advanced Requirements (23 Credits)**

**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.

<table>
<thead>
<tr>
<th>Basic</th>
<th>Advanced</th>
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<tbody>
<tr>
<td>BME 411 Cell &amp; Molec Bio Foundations*</td>
<td>ANA 531 Integrative Neuroscience (6)</td>
</tr>
<tr>
<td>BME 459 Applied Human Anatomy</td>
<td>BIO 419 Nuc Structure and Function</td>
</tr>
<tr>
<td>IND 408 Biochemistry</td>
<td>BIO 422 Biology of Aging</td>
</tr>
<tr>
<td>IND 409 Cell Biology</td>
<td>BIO 426 Developmental Biology</td>
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<tr>
<td>IND 410 Molecular Biology</td>
<td>BIO 428 Lab in Cell and Dev Biolo</td>
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<tr>
<td>MBI 414/514 Mech of Microbial Pathogenesis</td>
<td>CVS 401 Cardiovascular Bio and Disease (3)</td>
</tr>
<tr>
<td>PHP 403 Human Cell Physiology (3)</td>
<td>GEN 506 Principles in Stem Cell Biology</td>
</tr>
<tr>
<td>PHP 404 Principles of Pharmacology</td>
<td>GEN 507 Advanced Genetics</td>
</tr>
<tr>
<td>PTH 507 Cancer Biology (3)</td>
<td>GEN 508 Genes, Devel and Disease</td>
</tr>
<tr>
<td>PTH 509 Pathways to Human Disease</td>
<td>IND 407 Cytoplasmic Structures &amp; Functions</td>
</tr>
<tr>
<td>PTH 510 Pathways to Human Disease</td>
<td>IND 411 Methods in Structural Biology</td>
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<td>IND 443 Eukaryotic Genome I</td>
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<td>IND 447 Signal Transduction</td>
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<td></td>
<td>IND 525 Cell and Membrane Biophysics</td>
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<td></td>
<td>MBI 473 Immunology (3)</td>
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<td></td>
<td>NSC 512 Cellular Neuroscience (6)</td>
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<td></td>
<td>PHP 440 Topics in Vascular Biology (2)</td>
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<tr>
<td></td>
<td>PTH 571 Mol. Basis of Human Disease (3)</td>
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<tr>
<td></td>
<td>PTH 593 Nuclear Hormone Receptors (2)</td>
</tr>
<tr>
<td></td>
<td>TOX 521 Biochemical Toxicology</td>
</tr>
</tbody>
</table>

*Approval of instructor required.
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 465 Biomass Conversion to Fuels
- CHE 469 Biotechnology & Bioengineering
- CHE 480 Chemistry of Adv. Materials
- CHE 482 Processing Microelectronic
- CHE 486 Polymer Science & Tech
- CHE 492 Biointerfaces
- CSC 449 Machine Vision
- ME 400 Applied Boundary Value Problems
- 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 445 Precision Instrument Design
- 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 407 SEM Practicum
- OPT 411 Math/Theoret.
- OPT 421 Opt Properties of Semi-con
- OPT 425 Radiation & Detectors
- OPT 441 Geometrical Optics
- OPT 442 Instrumental Optics
- OPT 443 Found. of Mod Opt Systs
- OPT 444 Lens Design
- OPT 447 Adv Opt Coating Design
- OPT 452 Medical Imaging: Th.& Pract.
- OPT 461 Fourier Optics
- OPT 462 Physical Optics II
- OPT 463 Wave Optics & Imaging
- OPT 465 Laser Systems
- OPT 467 Non-Linear Optics
- OPT 476 Biomedical Optics
- 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 405 Adv Digital Design Using FPGA
- ECE 423 Semiconductors
- ECE 425 Superconductivity
- ECE 431 Microwaves & Wireless
- ECE 432 Acoustic Waves
- ECE 434 Microelectromechanical Systems
- ECE 435 Intro to Optoelectronics
- ECE 437 Wireless Communications
- ECE 440 Intro to Random Processes
- ECE 441 Detection & Estimation Theory
- ECE 444 Digital Communications
- ECE 446 Digital Signal Processing
- ECE 447 Digital Image Process
- ECE 450 Information Theory
- ECE 452 Med Imaging-Theor &Implmt
- 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 472 Audio Signal Processing
- ECE 585 Phy of Adv Opto-Electronic

Elective (4 credits)
This is free elective but should be relevant to a career in BME and must be approved by preliminary (1st year) exam committee.
D. Non-curricular 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. 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 page, table of contents, references, and appendices as needed. These pages do not count against a 13 page limit for the body of the proposal.

Font

- Use an Arial, Helvetica, Palatino Linotype or Georgia typeface, a black font color, 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.

Page Numbering

The proposal should be single-sided and single-spaced. Consecutively number pages throughout.

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 main document. Supplemental figures can be added to an appendix.

Proposal Sections (13 pages)

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. Restricted to 1 page.

B. Significance: Briefly sketch the background to the proposal and critically evaluate the existing knowledge. State concisely the importance of the research described in the proposal by explaining how the proposed project will improve scientific knowledge, technical capability, and/or clinical practice in one or more broad fields.

C. Innovation: Explain how the application challenges and seeks to shift current research or clinical practice paradigms. Describe any novel theoretical concepts, approaches or methodologies, instrumentation or intervention(s) to be developed or used, and any advantage over existing methodologies, instrumentation or intervención(s). Explain any refinements, improvements, or new applications of theoretical concepts, approaches or methodologies, instrumentation or interventions.
D. **Approach:** 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. Attempt to convince the reader, with preliminary data where possible, that you have a reasonable chance of achieving the aims in the proposed time. Discuss the potential difficulties and limitations of the proposed procedures and alternative approaches to achieve the aims.

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. 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.

**H. 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 25 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.)

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

I. Final Examination and Termination

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.
J. 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 – One Advisory Committee meeting is required per year.

Note: the expectation of the program is that students should not take more than six years to successfully complete the PhD. 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. The content of all courses has to be “advanced in content, rigor, and requirements.” A faculty member must review the program of study for any student with a course below 400-level and provide approval for including these courses. Specific credit requirements for each degree are summarized in the following table.

<table>
<thead>
<tr>
<th>Plan A</th>
<th>Plan B</th>
</tr>
</thead>
<tbody>
<tr>
<td>BST467 Applied Stats in Biomedical Sciences</td>
<td>BST467 Applied Stats in Biomedical Sciences</td>
</tr>
<tr>
<td>(3 credits)</td>
<td>(3 credits)</td>
</tr>
<tr>
<td>14 credits from:</td>
<td>14 credits from:</td>
</tr>
<tr>
<td>Advanced BME (4 credits minimum)</td>
<td>Advanced BME (4 credits minimum)</td>
</tr>
<tr>
<td>Approved Engineering (4 credits minimum)</td>
<td>Approved Engineering (4 credits minimum)</td>
</tr>
<tr>
<td>Approved Biology (4 credits minimum)</td>
<td>Approved Biology (4 credits)</td>
</tr>
<tr>
<td>IND501: Ethics in Research (one credit)</td>
<td>BME 496: Current Research Seminars (0 credit)</td>
</tr>
<tr>
<td>BME 496: Current Research Seminars (0 credit)</td>
<td>BME 496: Current Research Seminars (0 credit)</td>
</tr>
<tr>
<td>6-12 research credits</td>
<td>6-13 additional credits (6 research credits maximum)</td>
</tr>
<tr>
<td>30 credits total</td>
<td>30 credits total</td>
</tr>
</tbody>
</table>

Specific course descriptions, and lists of courses satisfying the Advanced BME, 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/](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: Masters 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 of 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 15th 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 retake 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.

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 11 credits of Approved Biology are waived. Additionally, only 4 credits of Advanced BME courses 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
- BST 467: Applied Statistics in the Biomedical Sciences (3 credits)
- 4 credits of Advanced BME
- The proposals writing course (2 credits; spring term)
- Research ethics (1 credit; fall term)
- BME 496: Current Research Seminars (0 credit)
- 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.