University of Vermont

DOCTOR OF PHILOSOPHY IN BIOMEDICAL ENGINEERING

Program of Study

Students will have a primary research advisor from the list of affiliated Biomedical Engineering faculty, and they must form a graduate studies committee by the end of the first year of enrollment. The student's graduate studies committee will be comprised of four regular members of the graduate faculty from both the *College of Engineering and Mathematical Sciences* and the *Larner College of Medicine* and should bridge both experimental and computational expertise. The chair of the graduate studies committee serves as the student's academic advisor and also as the dissertation advisor or supervisor. The committee should be approved by the BME Graduate Director and the Dean of the Graduate College. Committee members external to UVM must be approved by the Graduate College prior to serving. It is the responsibility of the graduate studies committee to supervise the graduate student's program and to review progress at regular intervals. Students must take at least 75 credits in courses and dissertation research including 14 credits of Core Courses, at least 16 credits of Technical Electives, and a minimum of 20 credits of dissertation research. To bolster their background in a particular area and with pre-approval from the Graduate College and the student's advisor, a Ph.D. student may apply up to six credits of (1xx) 2xxx, 3xxx, or 4xxx level coursework to their Ph.D. degree requirements.

Students are required to develop an **Individual Development Plan** (uvm.edu/graduate/resources) annually and discuss it with their primary advisor and graduate studies committee.

Biomedical Engineering Core Courses 14 credits

The core courses required of all Biomedical Engineering Ph.D. students are:

- Domain-Specific Courses (e.g., Adv. Bioeng. Systems, Complex Sys, or Biomaterials) (6 credits)
- Human Physiology (e.g. MPBP 301 (6010) Human Physiology & Pharmacology) (or equivalent) (4 credits)
- Mathematics or Statistics Course (3 credits)
- Research Ethics Course or equivalent (e.g. CEMS 301 (6010) Research Methods, Ethics, and Communication, NSCI 327 (6270) Responsible Conduct in Biomedical Research, PBIO 295 (3990) Ethics in Graduate Research, NFS 362 (6362) Intro to Research Methods) (1+ credit)

Note that students may pursue alternatives to any of the above core courses as befits the goals of their graduate training, but this requires approval from the BME Graduate Director. A student wishing to make a substitution should submit a justification in writing to the BME Graduate Director who will then seek approval from the BME Curriculum Committee and transmit this back to the student. The student should provide the following documentation when submitting their request: current copies of the syllabi of the course they are proposing to replace and its proposed replacement as well as a statement about why the proposed course would be more suitable for their research area. Ethics and rigor in research are paramount and cannot be overstated; advice on equivalent options if listed courses are not available should be sought from the BME Graduate Director.

Technical Electives (at least 16 credits)

Examples of possible elective courses are in the appendix. Students may take courses in areas germane to their research that are *not* included on this list with prior approval from their graduate studies committee.

Ph.D. Comprehensive Exam

The comprehensive exam for the Biomedical Engineering Ph.D. is typically taken by the end of a candidate's fourth semester of study and will consist of a written exam and an oral exam. Should the candidate fail the examination, only one reexamination is permitted.

The Written Exam

The written part of the examination will be a report written in the form of a research grant proposal (7-12 pages) and delivered to the student's graduate studies committee at least 2 weeks before the oral exam. The proposal will be based on a research idea in the candidate's dissertation work area and will comprise three Specific Aims. The first two aims will be focused on the area of the candidate's Ph.D. research and will be expected to include some preliminary data and a research plan that is grounded in techniques that the candidate understands well. The third aim will be a "stretch aim" that extends beyond the scope of the candidate's research. In this third aim, the candidate will be expected to exhibit evidence of an ability to generate imaginative and thoughtful hypotheses and to think laterally about how their Ph.D. research area could be developed in a new direction. The candidate should gain the approval of their graduate studies committee regarding the general area of the proposal before beginning work on it.

The report will follow the format of the research plan for an R01 grant submission to the NIH, although it is not expected that as much preliminary data will be included as would be expected for a typical R01. Detailed instructions about R01 proposals can be found at: https://grants.nih.gov/grants/how-to-apply-application-guide/forms-g/general-forms-g.pdf. However, for the purposes of the comprehensive exam, the R01 components that must be included in the report are:

A. Specific Aims (1 page): This gives an overview of the proposal and will typically provide an overarching hypothesis and/or goal, together with a maximum of 3 specific aims that are to be accomplished over a projected 5-year period of research.

B. Research Strategy (6-12 pages): This section provides a detailed description of the research that will be undertaken, including any figures and tables, and is divided into 3 sections.

   a) **Significance**. Describe how the proposed research is significant to the field of investigation as well as to bioengineering in general. Give appropriate background as needed to make the case.

   b) **Innovation**. Explain how the proposed research is novel. The Significance and Innovation sections are typically not more than 1 page together.

   c) **Approach**. This is the main body of the proposal and provides the preliminary data and experimental design necessary to support each specific aim. The Approach should address the hypothesis(es) and/or goal(s) put forward in the Specific Aims page. Appropriate statistical methods should be described, including calculations to justify sample sizes (i.e., power analysis) for experiments involving replicates.

C. References (no page limit)

These components must be prepared on 8.5 x 11-inch pages with 0.5-inch margins. The text should be in 11-point Arial font and line spacing set at 12 points. The proposal must deal substantively with both the engineering and the biological aspects of the proposed research. The engineering component will include a description of the project's design, analysis, and/or modeling aspects and must include appropriate attention to mathematical and statistical details. The biological component of the proposal should be hypothesis-driven and will explain the historical context of the project, the biomedical background that is appropriate, and the potential significance of the work. The proposal will also include:

a) alternative engineering methods that could be used on their biological question of interest (i.e., methods other than those to be used in the dissertation), and

b) alternative biological systems (other than those in the dissertation project) that could be studied using the engineering methods of the dissertation project.

These latter two aspects of the report will allow the student to demonstrate an ability to generalize both in terms of the application of engineering methods and approaches to biological problem-solving.

The Oral Exam

The oral part of the comprehensive examination will be a formal seminar by the student in front of their graduate studies committee, to take place after the committee members have had a chance to review the written proposal, which should be submitted at least 2 weeks before the oral presentation. The student will be asked to defend the proposal and to answer any additional questions the committee members feel appropriate after the seminar. It is expected that there will be specific questions directly associated with broad engineering and biomedical sciences.

After the oral part of the exam, the committee will meet to discuss both written and verbal components. The committee will then decide if the student can proceed to complete the Ph.D.; if the exam needs to be retaken, or (in the case of repeat failure), the student may be allowed to complete work for a master's degree. If successful, the Proof of Successful Completion of Comprehensive Exam form must be submitted to the BME Graduate Director and Graduate College.

Dissertation Proposal

Students will present a proposal around the end of the 6th semester (i.e., third year) of study. The proposal will take place in front of the candidate's dissertation committee, and it will be open to UVM students and faculty. Committee membership must meet the Requirements for the Doctor of Philosophy degree stipulations (https://catalogue.uvm.edu/graduate/degreerequirements/). The proposal meeting will begin with a statement of the ground rules for the meeting given by the committee chair and a brief introduction from the candidate's supervisor. The candidate will then give a presentation (typically 45 minutes) in which their research progress to date is outlined and plans for the completion of the dissertation are described.

The candidate must prepare a tentative table of contents for the dissertation with a brief paragraph describing what they anticipate will be the subject of each major chapter (including the focus of their literature review) and forward this to the committee at least 1 week prior to the meeting.

The candidate's presentation will be followed by questions from the audience and then questions from the dissertation committee in closed session. The committee will then deliberate in private after which its recommendations will be passed to the candidate. The entire dissertation proposal meeting will take roughly 90 minutes.

The purpose of the dissertation proposal is to satisfy the dissertation committee members that the candidate is on track toward the completion of their dissertation and that the research contained within it will meet the standards of scholarship and originality required for the Ph.D. degree. Note that the purpose of the dissertation proposal is not to conduct an in-depth examination of the candidate's research nor to make significant adjustments to the direction or nature of their research. The BME Graduate Director should be informed of the successful completion of the dissertation proposal.

Dissertation Defense

The Graduate College resources must be carefully utilized during this process; specifically, the Defense Committee Membership form, Intent to Graduate form, and Defense Notice form must be submitted in addition to conducting a format/record check. The Thesis/Dissertation Guidelines and Timetable, which are available on the Graduate College website, must be closely followed.

The dissertation defense examination committee consists of a minimum of 4 members of the graduate faculty. If a student has co-advisors, they count as one defense committee member. At least two graduate faculty members must be from inside the department or program. The chair must be both a member of the

graduate faculty and from outside the candidate's and advisor's department and program. The dissertation defense examination committee must be approved by the Graduate College prior to the defense. The dissertation defense examination committee and the graduate studies committee do not have to be the same.

The defense of a Ph.D. dissertation will take place at the discretion of the candidate and their supervisor at a point when the dissertation is complete and has been distributed (at least 2 weeks prior) to the members of the committee. A Public Notice of the defense is required at least 3 weeks prior to the scheduled defense date in order for the student to defend.

The defense will begin with a statement of the ground rules for the meeting given by the committee chair and a brief introduction from the candidate's supervisor. The candidate will then present their research in about 1 hour. This will be followed by questions from the audience and then questions from the examining committee in a closed session. The committee will then deliberate in private after which its recommendations will be passed to the candidate. The entire dissertation defense will take 2-3 hours. If a student's defense examination performance is not satisfactory, then one reexamination, and one only, is permitted.

APPENDIX

Table. Electives appropriate for BME graduate programs of study

Engineering	***Biosciences and other***
BME/EE 227 (3710) Biomedical Instrumentation	MPBP 310 (6100) Molecular Control of the Cell
BME/EE 229 (3720) Biosignal Decoding	MPBP 330(6300) Biomedical Grantsmanship
BME 240 (3740) Wearable Sensing	BIOC 205 (3005) Biochemistry I
BME 241 (3750) Biomedical Signal Processing	BIOC 206 (3006) Biochemistry II
BME 250 (5150) Nanobiomaterials	BIOC 275 (3075)Adv Biochemistry of Human Disease
BME 396 (6990) Special Topics	BIOC 301 (6001) General Biochemistry I
ME/BME 201 (3410) Biomaterials Engineering	BIOC 302 (6002) General Biochemistry II
ME/BME 204 (5440) Biothermodynamics	BIOC 372 (6072) Cancer Biology
ME/BME 206 (3460) Biomechanics of Human Motion	MMG 211 (3110) Prokaryotic Molecular Genetics
ME/BME 208 (3480) Biomechanics: Tissue Engineering	MMG 222 (3220) Advanced Medical Microbiology
BME 6710 Brain-Computer Interfaces	MMG 223 (3230) Immunology
ME 249 (3530) Computational Fluids Engineering	MMG 231 (3310) Bioinformatics & Data Analysis
ME 252 (5110) Mechanical Behaviors of Materials	MMG 232 (3320) Advanced Bioinformatics
ME 255 (5120) Advanced Engineering Materials	MMG 320 (6200) Cellular Microbiology
ME 257 (3180) Composite Materials	BIOL 261 (3505) Neurobiology
ME 271 (5370) Micro and Nano Systems	BIOL 270 (4265) Speciation and Phylogeny
ME 312 (5410) Advanced Bioengineering Systems	BIOL 271 (3165) Evolution
ME 338 (6120) Advanced Dynamics	CLBI 295(5990)Adult Stem Cells & Regenerative Med
ME 336 (5160) Continuum Mechanics	CLBI 301 (6010) Cell Biology
EE/ME 210 (3320) Control Systems	CLBI 401 (7010) Critical Reading and Analysis
EE 221 (5410) Real Time Control Systems	CLBI 402 (7020) Biomedical Data Analysis
EE 228 (3920) Sensors	PHYS 301 (5125) Mathematical Physics
EE 275 (3530) Digital Signal Processing	PHYS 333 (6700) Biological Physics
CE 201 (4710) Sustainable Eng Materials	HLTH 241 (3410) Exploring Healthcare Systems
CE/ME (5980) 218 Numerical Methods for Engineers	
CE 256 (5560) Biol Proc Water/Wastewater Treatment	
Computational Science and Mathematics	***Statistics***
CS 228 (3280) Human-Computer Interaction	STAT 200 (3000) Med Biostatistics & Epidemiology
CS 253 (3530) QR: Reinforcement Learning	STAT201(3010)StatisticalComputing & Data Analysis
CS 254 (3540) QR: Machine Learning	STAT 3210 Advanced Statistical Methods
CS/CSYS 302 (6020) Modeling Complex Systems	STAT 231 (5310) Experimental Design
CS/CSYS 352 (6520) Evolutionary Computation	STAT 5210 Advanced Stat Methods and Theory
CSYS/CE 395(6990) Applied Artificial Neural Networks	STAT 235 (5350) Categorical Data Analysis
CSYS/STAT/CE 369 (7980) Applied Geostatistics	STAT 241 (3410) Statistical Inference
MATH 237 (3737) Numerical Methods	STAT 251 (5510) Probability Theory
MATH 337 (6737) Numerical Diff Equations	STAT 253 (5530) Applied Time Series & Forecasting
ME 304 (5040) Adv Engineering Analysis I	STAT/CS/CSYS 287 (3870) Data Science I
ME 305 (6040) Adv Engineering Analysis II	
MATH 266(3766) Chaos, Fractals & Dynamical Systems	
MATH 268 (5788) Mathematical Biology & Ecology	
MATH 303 (6713) Complex Networks	