DOCTOR OF PHILOSOPHY IN BIOENGINEERING

CURRICULUM

Revised: 02-12-13

Requirements for Admission

Prospective students must apply to the Bioengineering PhD program through the UVM Graduate College. Three letters of reference are required. Letters from research advisors or supervisors are highly desirable, and should attest to the applicant's ability to work independently in an academic setting. A complete application for Fall admission must be received by **January 15**.

Students entering the Bioengineering PhD program should have a degree in an appropriate field of study and should have demonstrated academic performance as measured by grades and satisfactory scores on the Graduate Record Examination (GRE). Non-native English speakers need a TOEFL score above 7 (new system) or 90 (old system) for entry into the program. Prior coursework in engineering, computational science, and/or the life sciences is highly desirable. The ideal applicant will have a broad technical background encompassing engineering, mathematics (including differential equations and linear algebra), and science (including physics and chemistry). Specific remedial coursework may be required of those who lack a sufficiently strong background in certain areas.

Retention in the Program

For retention, students must maintain good academic standing and must continue to progress towards their PhD degree requirements. In addition, students must participate in seminars and reading clubs, as appropriate. Students will be required to pass a comprehensive exam, as described below, in order to move on to the final thesis stage of their PhD requirements.

Programs of Study

Students will have a primary advisor from the list of affiliated bioengineering faculty, and must form a program committee containing faculty from both the *College of Engineering and Mathematical Sciences* and the *College of Medicine*. The committee must include faculty with both experimental and computational expertise.

<u>Bioengineering Core Courses 17 credits</u>

The core courses required of all bioengineering PhD students will be:

- ME312 Advanced Bioengineering Systems (3 credits)
- MPBP 301 & 302 (or equivalent) Human Physiology (8 credits)
- CS 302/CSYS 302 (or equivalent) Complex Systems Modeling (3 credits)
- Advanced Math of Stats Course (3 credits)

Technical Electives (at least 13 credits)

Examples of possible elective courses are listed below.

Engineering

- ME 207 Biomechanics I
- ME 208 Biomechanics II
- ME 209 Biofluids
- EE 227 Biomedical Measurements, Instrumentation and Systems
- ME 249 Computational Fluids Engineering
- ME 252 Mechanical Behaviors of Materials
- ME 257 Composite Materials
- ME 338 Advanced Dynamics
- ME 336 Continuum Mechanics
- EE 210 Introduction to Control Systems
- EE 275 Digital Signal Processing
- EE 276 Image Processing
- EE 270 Stochastic Processes
- CE 220 Finite Element Analysis
- CE 256 Biol Proc Water/Wastewater Treatment

Computational Science

- CS 231 Bioinformatics
- CS 251 Artificial Intelligence
- CS 256 Neural Computing
- CS 260 Parallel Computing
- CS 352 Evolutionary Computation
- CS 355 Statistical Pattern Recognition
- CS 331 Data Mining
- MATH 221 Operations Research
- MATH 237, 274 Numerical Methods
- MATH 337 Numerical Diff Equations

Mathematics

- ME 304 Adv Engineering Analysis I

- ME 305 Adv Engineering Analysis II
- MATH 266 Chaos, Fractals & Dynamical Systems
- MATH 268 Mathematical Biology & Ecology
- MATH 295 Complex Networks

Statistics

- STAT 231 Experimental Design (Same as Biostatistics 231.)
- STAT 233 Survey Sampling (Same as Biostatistics 233.)
- STAT 235 Categorical Data Analysis (Same as Biostatistics 235.)
- STAT 237 Nonparametric Statistical Methods (Same as Biostatistics 237.)
- STAT 241 Statistical Inference (Same as Biostatistics 241.)
- STAT 251 Probability Theory
- STAT 252 Applied Discrete Stochastic Processing Models
- STAT 253 Applied Time Series & Forecasting (Same as Biostatistics 253.)
- STAT 254 Applied Continuous Stochastic Processing Models

Biosciences and other

- MPBP 295 Medical Physiology
- MPBP 310 Molecular Basis of Biological Motility
- MPBP 323 Biophysical Techniques
- BIOC 205 Biochemistry I
- BIOC 206 Biochemistry II
- BIOC 301 General Biochemistry I
- BIOC 302 General Biochemistry II
- BIOC 370 Physical Biochemistry
- MMG 203 Mammalian Cell Culture: Molecular Biology
- MMG 211 Prokaryotic Molecular Genetics
- MMG 240 Macromolecular Structure of Proteins & Nucleic Acids
- MMG 352 Protein:Nucleic Acid Interactions
- BIOL 261 Neurobiology
- BIOL 270 Speciation and Phylogeny
- BIOL 271 Evolution
- BOT 252 Molecular Genetics II

- CLBI 295 Adult Stem Cells & Regenerative Med
- CLBI 301 Cell Biology
- CLBI 302 Specialized Cells & Cell Processes
- PHYS 301 Mathematical Physics

Comprehensive Exam

The comprehensive exam for the Bioengineering PhD will be taken at the end of a candidate's forth semester of study (typically around May of Year 2) and will consist of a written part and an oral part.

The Written Part

The written part of the examination will be a report written in the form of a research grant proposal. The proposal will be based around a research idea in the area of the candidate's thesis work, but which is clearly different from their supervisor's funded research program. This will ensure that the report is not simply a reiteration of something already in existence, while at the same time allowing the candidate to use their already reasonably deep understanding of an area of research, and to think laterally about how this area might be developed laterally to take it in a new direction. The candidate should gain the approval of their thesis committee regarding the general area of the proposal prior to beginning work on it.

The report will follow the format of the research plan for a 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:

http://grants.nih.gov/grants/funding/424/SF424_RR_Guide_General_Adobe_VerB.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 as follows.

   a) **Significance**. Describe how the proposed research is significant to the field of investigation as well as to biomedicine 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 much 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, as appropriate, including calculations to justify sample sizes (i.e. power analysis) for experiments involving replicates.

C. References (no page limit)

These components are to be prepared on 8.5 x 11 inch pages with 0.5 inch margins all around. The text should be in 11 point Ariel font.

The proposal must deal in a substantive way with both the engineering and the biological aspects of the proposed research. The engineering component will include a description of design, analysis and/or modeling aspects of the project, 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, any biological background that is appropriate, and will state those hypotheses to be tested as well as the potential significance of the work. The proposal will also include:

(a) a discussion of the way in which the theory or philosophy of complex systems bears on the project,

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

c) 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 application of engineering methods and approaches to biological problem solving.

The Oral Part

The oral part of the comprehensive examination will be a formal seminar by the student in front of their advisory committee, to take place after the committee members have had a chance to review the written proposal, which should be in the hands of the committee members at least 2 weeks prior to 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 biological sciences, as well as complex systems analyses and approaches.

After the oral part of the exam, the committee will meet to discuss both written and oral components. The committee will then decide if the student can proceed to complete the PhD, 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.

Research ethics

At some point during their studies, students must attend a course in research ethics such as ANNB/Path 327: Responsible Conduct in Research, or BIOL 381: Integrity in Science.