DOCTOR OF PHILOSOPHY DEGREE IN BIOMEDICAL ENGINEERING.

I. Introduction:

Biomedical Engineering (BME) is an interdisciplinary field that is based on the application of engineering principles and experimental and analytical techniques to the development of biologics, materials, devices, implants, processes and systems that advance biology and medicine and improve medical practice and health care.

The Doctor of Philosophy (PhD) degree in BME is a research degree that is intended to provide the graduate with the breadth and depth of knowledge in one area of specialization within BME, as well as the scientific research training needed for successful careers in academia, biomedical industry, or government. The research training process begins with the student working closely with his or her Dissertation Director and participating in his or her research program. Building on these experiences, the student begins to conduct independent research that eventually leads to an original contribution to the BME field. The strength and efficacy of the training process depend to a large extent on the direct interactions of the student with his or her Dissertation Director and on the time the student spends in the laboratory working on his or her research. The importance of this research training to a PhD degree in BME is underscored in the following learning objectives that were developed to evaluate the efficacy of the PhD program in BME.

- *Conduct independent research that reflects an original contribution to BME.*
- *Demonstrate technical proficiency in at least one area of BME.*
- *Recognize the need to apply ethical principles in conducting research.*
- *Demonstrate a commitment to life-long learning by participating in local and national professional development activities on a continuing basis.*

Students in the Medical Scientist Training Program (**MSTP;** a combined **MD/PhD** degree program) at MCW are eligible to choose the PhD program of the joint MU-MCW Department of BME for the PhD requirements of the MD/PhD degree program.

MSTP students begin their curriculum at MCW with two full years of medical school (M1 and M2 years), during which they complete a large array of clinical, translational, and basic science coursework, equivalent to an MS degree. During their M1 and M2 years, they also complete four one-month long laboratory rotations during which they gain valuable research experience. These lab rotations are intended to help MSTP students to choose a lab and a research area (by the end of their M2 year) for conducting their PhD dissertation research. Following their M1 and M2 years, MSTP students typically spend three to four years in graduate school, working toward their PhD dissertation before returning to the medical school to complete their medical training.

II. Specializations/Tracks:

1. *Bioinstrumentation*
2. *Biomechanics*
3. *Biomedical Imaging*
4. *Cellular and Molecular Engineering*
5. *Computational Biology and Bioinformatics*
6. *Rehabilitation Bioengineering*

III. Admission Requirements:

1. Educational Background.

Graduates of accredited colleges or universities with a Bachelor's (BS) or Master's (MS) degree in various engineering, physical science, or life science disciplines or equivalent are eligible for admission to the joint MU-MCW PhD program in BME.

The time constraints to which **MSTP students** adhere (i.e. three to four years of graduate school) preclude them from completing any pre-requisite/leveling courses that may not have been completed as part of their undergraduate education. Therefore, MSTP students interested in the MU-MCW BME Department PhD program must have an undergraduate degree in some field of engineering.

2. Pre-requisite Coursework for Students Enrolling Without a BME Degree.

Students who do not have a BME degree are admitted into the PhD program on a conditional status based on successful completion (grade of B or better) of a sequence of leveling courses. These courses will provide them with fundamental engineering principles and analytical skills needed for successful completion of the PhD degree in BME. The following is a list of pre-requisite leveling courses:

- ***Mathematics:*** Calculus through Differential Equations
- ***Programming:*** Knowledge of a high-level computer programming language (e.g. C, C++, Java, Python, MATLAB, R, FORTRAN)
- ***Basic Sciences:*** A minimum of 3 courses from: Calculus-based Physics, Biology (for scientists/engineers), Physiology, or Biochemistry subject to at least one in Physics and one in Biology.
- ***Engineering Sciences:*** 4 courses from the following list of 12 offered at MU:

Circuits 1	e.g., EECE 2010	**Statics and Dynamics**	e.g., MEEN 2122
Circuits 2	e.g., EECE 2020	**Materials Science**	e.g., MEEN 2460 or 3460
Analog Electronics	e.g., EECE 3030	**Mechanics of Materials**	e.g., MEEN 2130
Digital Electronics	e.g., EECE 2030	**Fluid Dynamics**	e.g., MEEN 3320 or 4320
Linear Systems	e.g., EECE 3020	**Thermodynamics**	e.g., MEEN 3310
Data Structures	e.g., COSC 2010	**Computer Hardware**	e.g., COEN 4710

Equivalent courses completed prior to application to the PhD program can be used to satisfy these pre-requisite courses.

To gain regular status, a student must complete these pre-requisite courses during the first year with grade of B or better. Cost effective online courses could be used to satisfy these pre-requisite courses. Approval from the Director/Co-Director of BME Graduate Studies (DGS/Co-DGS) is needed prior to enrolling in online courses. Graduate tuition waiver does not cover these pre-requisite courses.

3. Application for Admission.

All applicants for the MU-MCW doctoral program in BME must file the following documents with the MCW Graduate School. Normally, files are not considered for admission until they are complete. Priority deadline for completed applications for fall admission is December 15th. The requisite materials are:

- Application for Admission.

- Official transcripts of undergraduate and graduate records, sent directly to the MCW Graduate School by the institution concerned. A GPA of 3.0 or higher is required for admission. Foreign transcripts submitted may include an evaluation/translation to determine equivalencies. If a transcript or mark sheet is not in English, the applicant must supply a translation.
- Results of the GRE General (Aptitude), sent directly to the MCW Graduate School by the Educational Testing Service (www.ets.org).
- Three letters of recommendation and recommendation form including references from recent teachers and/or supervisors.
- A "*Statement of Purpose*" in which the student indicates his or her reasons for seeking the doctoral degree in BME, declares his or her areas of interest (from the above six Specifications/Tracks), and identify BME faculty (up to three in the order of preference) he/she would be interested in working with for dissertation research.
- Evidence of research ability, if available (e.g. copy of independent study research reports, undergraduate Honor's thesis, MS thesis, reprints of manuscripts, conference abstracts).
- Application fee (non-refundable).
- International students must submit results of TOEFL examination, sent directly to the MCW Graduate School by the Educational Testing Service (www.ets.org). International students who are in the process of completing or have completed their undergraduate degree in the United States, United Kingdom, Australia, New Zealand or Canada (excluding Quebec) are not required to take the TOEFL examination.

Admission is not official until the student is notified in writing of acceptance by the MCW Graduate School. Students who cannot matriculate following admission to the PhD program can request deferment for up to one year. Acceptance will be withdrawn for students who do not enroll and fail to request deferment of admission.

Students with an MS degree from MU or MCW interested in pursuing a PhD degree in the MU-MCW BME PhD program must submit a new application to the MCW Graduate School.

MSTP students at MCW wishing to pursue a PhD degree in BME need not formally apply to the MU-MCW BME PhD program. Instead, they must satisfy the following requirements prior to pursuit of the BME PhD degree:

- The student must identify an Academic Advisor with a primary or secondary/adjunct appointment in the MU-MCW BME Department prior to the start of their BME PhD degree (typically, by the end of their M2 year). MSTP students typically begin their PhD degree program in the summer or fall semester following their M2 year. The Academic Advisor must express his or her consent for accepting the student into his or her lab in writing to the student, the MSTP Program Director, the Director/Co-Director of BME Graduate Studies (DGS/Co-DGS), and the BME Department Chairperson. The writing could be through an email to the student, cc'ing other officials involved.
- The student must meet with and obtain approval from the DGS/Co-DGS prior to entry into the BME PhD Program.
- The Academic Advisor and the DGS/Co-DGS will need to ensure that the student satisfies all the eligibility criteria, including undergraduate academic background, for pursuing a PhD degree in BME.

4. Transfer of Credits.

The transfer of credits completed at the graduate level at another institution is handled on an individual basis. No more than 18 graduate-level credit hours will be accepted for transfer into the MU-MCW BME PhD program. The 18 credits hours include coursework taken at MU and/or MCW prior to admission and credits earned at other institutions before or during enrollment in the MU-MCW BME PhD program. Credits are eligible for transfer only if **a**) the grade earned is a B or better (3.0 on a 4.0 scale), **b**) earned no more than five years before the start of the MU-MCW BME PhD program, and **c**) are not used as a part of the requirements for another degree (e.g. MS degree). Pass/Fail courses are not eligible for transfer. Students need to complete the MCW Transfer of Credits form (*https://infoscope.mcw.edu/Graduate-School-Intranet.htm*).

Graduate credits used as a part of the requirements for another degree (e.g. MS degree) and earned no more than five years before the start of the MU-MCW BME PhD program could be used to waive the pertinent didactic coursework requirements. The students still need to satisfy the 60 graduate credits requirement of the MCW Graduate School by taking additional reading and research courses.

Graduate credits earned more than five years prior to the start of the MU-MCW BME PhD program could be used to satisfy equivalent pre-requisite leveling courses. Any graduate student contemplating course work at another institution with the intent of transferring credits into the joint MU-MCW doctoral program should seek prior approval from the Director/Co-Director of BME Graduate Studies and the MCW Graduate School.

IV. Program Requirements:

The PhD degree in BME is conferred in recognition of marked ability and high attainment in the advancement of knowledge and pursuit of truth in the field. It is never awarded solely as a result of course work completed, no matter how faithfully extended over any prescribed period of time. In defining the requirement for this degree, it is convenient to use semester credits, but it should be clearly understood that no number of credits alone entitles a student to this degree. The comprehensive knowledge expected of the student in his or her major field is such that the requirements for the degree usually demand no less than four years of full-time work or the equivalent beyond the BS degree.

1. Academic Status:

The joint MU-MCW PhD program in BME is administered through the MCW Graduate School of Biomedical Sciences, and hence doctoral students need to abide by the policies as laid out in the MCW Graduate School Handbook.

A doctoral student can only receive tuition waiver and stipend if he or she maintains a full-time status throughout the PhD program and satisfactory academic progress. Traditionally this means that 100% of the student's activity is devoted to the PhD program. Thus, full-time students are not allowed to hold part-time work outside of the academic environment that would interfere with their doctoral work. Full-time also means 24 credits a year, which is split into 9, 9 and 6 credits for fall, spring and summer, respectively. This could be a combination of coursework and reading and research credits (see *Graduate Credits* below). If a student does not take a full credit load, he or she is not eligible for stipend or tuition waiver. Doctoral students need to be continuously enrolled for the duration of their study at a full-time level, but a student may take a Temporary Withdrawal (a.k.a. Leave of Absence) if he or she needs to temporarily drop out of the PhD program for an extended time for personal reasons.

2. **Doctoral Program Planning Form.**

A program of study leading to the PhD degree in BME must be prepared by the student in consultation with the student's Academic Advisor or Dissertation Director, if already chosen. The proposed program of study is outlined on the *Doctoral Program Planning Form* (*https://www.marquette.edu/grad/documents/doct-prog-planning-092010.pdf*) and should be submitted to the Director/Co-Director of BME Graduate Studies by the student at the end of the student's first semester of study, if possible, but no later than the end of the second semester of course work. Course work is accepted as part of a student's doctoral program only after approval of the Doctoral Program Planning Form. The form requires the approval of the student's Academic Advisor (or Dissertation Director), the Director/Co-Director of BME Graduate Studies, and the BME Department Chairperson. Any change to this plan requires approval at all the levels indicated above. The "Doctoral Program Planning Form Amendment Recommendation" is provided for this purpose.

3. **Graduate Credits.**

A minimum of 60 graduate credits are required to complete the PhD degree in BME. For someone entering with a BS degree, this constitutes 36 credits in didactic coursework, 9 credits in dissertation, and a minimum of 15 credits in reading and research. For those entering with an MS degree or with Graduate credits (see Transfer of Credits Policy), they are required to complete a minimum of 18 credits in didactic coursework, 9 credits in dissertation, and a minimum of 33 credits in reading and research. Pre-requisite courses for applicants who do not have a BME degree are not counted as graduate credits. Reading and research credits can be earned by registering and attending a seminar series, workshop, conference, journal club, or simply carrying dissertation-related activities. A student can register for up to 9 credits of reading and research per semester during fall and spring semesters and up to 6 credits during the summer. Students should register for dissertation credits in the semester they intend to defend their dissertation.

The graduate credits didactic coursework should include formal courses as defined at the end of this Handbook, and consist of:

- ***Core course requirements (17 credits):*** All doctoral students must complete courses that satisfy the following competencies:
  - **Systems physiology** (3 credits) *(e.g. BIOL 5703, BIEN 5700, BIEN 5720, BIEN 6391, MCW Physiol 08204)*
  - **Biostatistical methods** (3 credits) *(e.g. MSCS 5720, MSCS 5740, MCW courses: BioStat 04224, BioStat 04231, BioStat 04232, BioStat 04233, BioStat 04363, BioStat 04365)*
  - **Biomedical signal processing** (3 credits) *(e.g. BIEN 5510, BIEN 6200, BIEN 6210, BIEN 6220, MCW Biophys 03240)*
  - **Bioethics** (2 credits) *(MCW BIOETHICS 10222, MCW BIOETHICS 10444). Both courses (1 credit each) are required for all doctoral students.*

- **Advanced engineering mathematics** (3 credits) *(e.g. EECE 6010, MEEN 6101, BIEN 6500)*
- **Computational and simulation methods** (3 credits) *(e.g. BIEN 5710, BIEN 6620, MCW Physiol 08284, MCW Physiol 08285)*

- ***Specialization-specific courses (19 credits):*** Selected in consultation with the student's Dissertation Director. See the end of this document for a non-exhaustive list of pertinent graduate courses offered at MU and MCW.

- PhD students and **MSTP students** in the BME Department are also required to register for the BME Department seminar series for the duration of their study (BIEN 6953, which counts for 1 credit/semester of reading and research). For a given semester, students are expected to attend at least two thirds of the seminars.

The *Doctoral Program Planning Form* should include a list of the courses that the student intends to take to satisfy the BME core course requirements.

MSTP students in the BME PhD program must also earn a minimum of 60 graduate credits for obtaining the PhD degree. This includes a minimum of 18 credits in didactic coursework, 9 credits in dissertation, and a minimum of 33 credits in reading and research. The number of didactic courses for MSTP students is reduced from 36 to 18 credits due to the wealth of didactic coursework that MSTP students take during their M1 and M2 years. The 18 credits of required didactic coursework could be a combination of BME core and specialization-specific courses. Additional didactic coursework beyond the required 18 credits may be taken if deemed beneficial to the student's research and training. **MSTP students** are required to demonstrate that they possess all core competencies.

Upon entry into the BME PhD program, an **MSTP student** is required to consult with his or her Academic Advisor to determine which didactic courses (BME core and specialization-specific courses) are most appropriate for his or her dissertation research and training and gaining BME core competencies. The identified didactic courses (minimum of 18 credits) should be listed on the student's *Doctoral Program Planning Form*.

4. **Grades.**

Satisfactory academic work is not determined exclusively by the didactic coursework grades. However, grades are one important factor in the evaluation process. The minimum standard for graduation is a cumulative GPA of 3.0 (out of 4.0) and a GPA of 3.2 in core competency courses. Students with a cumulative GPA under 3.0 and/or a GPA under 3.2 in core competency courses are automatically placed on probationary status. Probationary status may only occur once during a student's academic career in the MCW Graduate School. See the following link for more information about the MCW Graduate School probation policy. See pages 14-15 of this document regarding MCW Graduate School's expectations for the students' performance in the reading and research credits and the associated grading policy.
https://www.mcw.edu/-/media/MCW/Education/Academic-Affairs/MCW-All-Student-Bulletin.pdf

5. **Doctoral Dissertation Outline Form.**

Before deciding to take up the Doctoral Qualifying Examination (DQE), the student must meet with his or her Dissertation Director to identify a Doctoral Dissertation Committee. A document listing the requested committee members (*Dissertation Committee Approval Form*) must be forwarded to the Director/Co-Director of BME Graduate Studies, the BME Department Chairperson, and the Dean of MCW Graduate School for reviewing and approval. The Dissertation Committee Approval Form must be approved by the student's Dissertation Director, the BME DGS/Co-DGS, the BME Department Chairperson, and the Dean of MCW Graduate School before the student can take the DQE.

6. **Doctoral Dissertation Committee.**

The Doctoral Dissertation Committee consists of a Dissertation Director, at least four additional voting committee members, and additional advisory committee members, as needed. The Committee must be designed to represent expertise in the research area(s) of the dissertation. At least three committee members must hold regular (i.e. primary or secondary/adjunct) appointments in the joint MU-MCW Department of BME, two of which should hold primary appointments. The Dissertation Director must be a regular faculty member in the MU-MCW Department of BME. Dissertation Director must also have an MCW Graduate School Faculty Member Appointment at the PhD level. The Dissertation Director will assure that the appropriate paperwork is filed for the dissertation and assure that graduation requirements are met.

A voting Dissertation Committee member without a regular appointment in the MU-MCW Department of BME must meet the following qualifications:

- Curriculum Vitae on file in the Department's Office.
- Approval of the Dissertation Director.
- A terminal degree in the Committee Member's chosen profession.
- Recognized expertise in the area(s) of the dissertation.

The Graduate Committee of the MU-MCW Department of BME must approve any exceptions to these qualifications for voting members.

7. **Doctoral Qualifying Examination.**

Doctoral Qualifying Examination (DQE) is intended to be both diagnostic and prognostic. The objectives are to evaluate the student's **a**) breadth and depth of knowledge in the chosen area of specialization, and **b**) ability to apply basic engineering principles and analytical tools to address integrative questions in BME topics related to the chosen area of specialization. Students on probation are not eligible to take the DQE.

The DQE consists of two parts. The first part involves writing a dissertation proposal in the form of an NIH-style F30/F31 fellowship grant proposal and submitting it to the student's Dissertation Committee. The second part is an oral examination, involving the student's presentation and defense of the dissertation proposal, in which the Dissertation Committee members serve as examiners. The student must submit a dissertation proposal and pass the oral examination to advance to *doctoral candidacy*.

Students entering the PhD program with a BS degree are encouraged to take the DQE at or before the completion of 30 graduate credits of didactic coursework. **MSTP students** and students entering the PhD program with an MS degree are encouraged to take the DQE at or before the completion of 15 graduate credits of didactic coursework. Given the time constraints to which **MSTP students** must adhere, they are strongly advised to take the DQE and advance to *doctoral candidacy* by the end of their first year in the BME PhD program.

If the student fails the DQE, he or she will be given one additional chance to retake it, normally within 6 months or 2 semesters of the first attempt. If the second attempt is unsatisfactory, no further oral examination is permitted. Those students who fail the second attempt are permitted to complete a joint MU-MCW MS degree (thesis-based) in BME administered by MU. The student's dissertation proposal and the *DQE Evaluation Forms* completed by each member of the student's dissertation committee become a part of the student's permanent file in the Office of the joint MU-MCW Department of BME.

A. Dissertation Proposal.

Before taking the oral examination, the student must prepare a detailed dissertation proposal (NIH-style F30/F31 fellowship grant proposal covering specific aims and hypotheses, background and significance, innovation, preliminary data, and research methodology including scientific rigor and statistical analysis). The proposal should be appended to a completed *Doctoral Dissertation Outline Form*. The dissertation proposal should clearly state the research problem to be addressed; give a cogent perspective of the problem relative to the state of the art; discuss the methods proposed to solve the problem; and discuss the expected results, potential difficulties, and alternative approaches. As a guide, the dissertation proposal should be approximately 7 pages in length (NIH-style font, size, margins, and spacing), which is the length of an NIH fellowship grant proposal (F30/F31). The student is required to send a copy of his or her dissertation proposal to each member of his or her Dissertation Committee at least two weeks prior to taking the oral examination.

B. Oral Examination.

The principal focus of the oral examination will be the dissertation proposal and BME core competencies. Again, it is to be both diagnostic and prognostic, as detailed above. It is recommended that the oral examination not exceed three hours in duration.

The oral examination requires that the student present his or her dissertation proposal to the Dissertation Committee, followed by an extensive question-answer (QA) session on the dissertation proposal and BME core competencies. Again, the objectives of the QA session are to evaluate the student's **a**) breadth and depth of knowledge in the chosen area of specialization, and **b**) ability to apply basic engineering principles and analytical tools to address integrative questions in BME topics related to the chosen area of specialization. At the end of the QA session, the student and his or her Dissertation Director will be asked to leave the room. The Dissertation Committee members will then discuss the student's performance and determine if he or she has gained the requisite core knowledge and skills needed to complete the proposed work. At the end of this discussion, the Dissertation Committee members will take a vote (**secret ballot**) on whether to pass or fail the student. A majority of "pass" votes is needed for the student to pass the oral examination and advance to *doctoral candidacy*.

At the end of the oral examination, a *DQE Evaluation Form* should also be completed by each member of the Dissertation Committee and submitted by the Dissertation Director to the BME DGS/Co-DGS and MCW Graduate School. In the *DQE Evaluation Form*, each Dissertation Committee member should identify the areas of weakness in the student's dissertation proposal and oral examination. Through this process, the Dissertation Committee members will also identify any additional didactic coursework necessary to fill potential knowledge gaps required to prepare the student for ongoing research and training. Prescriptions to address the perceived weaknesses should be included in the *DQE Evaluation Form*.

If the student passes the oral examination, the *Dissertation Outline Approval Form* along with the approved dissertation proposal must be completed by the Dissertation Director and submitted to the MCW Graduate School.

After advancing to *doctoral candidacy*, students should register for the required 9 hours of dissertation credits in the semester they are expected to defend their PhD dissertation. There must be at least of 18 months of duration between the student's advancing to candidacy and defense of their PhD dissertation.

8. Academic Progress and Evaluation of Performance.

- Doctoral students within the joint MU-MCW Department of BME shall present a summary of their research progress to their Dissertation Committee on an annual basis, commencing in the spring semester after passing the doctoral candidacy examination.
- At the annual meeting (following the student presentation), the Dissertation Committee shall jointly complete a departmental assessment of the graduate student's progress. The Dissertation Committee shall make a determination as to whether student progress is satisfactory or unsatisfactory and whether or not the student should be allowed to continue in the BME PhD program.
- Following the meeting, the Dissertation Director shall draft a brief summary of student performance (20-100 words) to be submitted with the department assessment form to the Graduate Committee of the BME Department for review. The summary should also be submitted to the MCW Graduate School. In addition, the MCW Graduate School requires that the student meet with his or her Dissertation Director on an annual basis to complete an assessment rubric (MCW Graduate School form) to be submitted to the MCW Graduate School.
- Based on the student's academic work (cumulative GPA of at least 3.0 and a GPA of 3.2 in core competency courses) and progress and performance (annual progress reports from student's dissertation committee), the BME Graduate Committee shall recommend to the BME Department Chairperson and the Academic Standing Committee as to whether the student is performing satisfactory work. If the student is not performing satisfactory work, the Graduate Committee and the Academic Standing Committee will recommend one of the following:
  - A probationary period of two semesters.
  - Transfer to the MS program in BME at MU.
  - Withdrawal from the BME PhD program.
- If a student is not performing satisfactory work, the student, Dissertation Director, Academic Advisor, Academic Standing Committee, and the Dean of MCW Graduate School will be notified in writing by the Department Chair. The student may be placed on probation for two semesters, advised to transfer to the MS program in BME at MU, or counseled to withdraw from the BME doctoral studies. The proposed program will follow MCW Graduate School probationary policy.

9. Publications:

PhD students are required to submit at least one first-authored manuscript to a refereed journal in the field based on their doctoral dissertation work prior to their public defense of dissertation.

10. Public Defense of Dissertation.

An acceptable doctoral dissertation must meet each and all of the following 3 conditions:

- The dissertation must represent an original research contribution as determined by the student's Dissertation Director and Committee members.
- The dissertation must show a high degree of achievement and a clear ability to do independent research.
- The format of the dissertation must follow the "Dissertation Directives" issued by the MCW Graduate School.

When the student and his or her Dissertation Director consider the dissertation to be in appropriate form, the student should submit a copy to each member of the Dissertation Committee. This should be done a minimum of 4 weeks (30 days) before the scheduled final examination. Preliminary copy of the dissertation should also be sent to the MCW Graduate School at least 2 weeks prior to the defense. In addition, a dissertation defense announcement should be sent to the Graduate School at least 30 days prior to defense. It is the obligation of the student to arrange a time and place on the MU or MCW campus for the final examination and to prepare an official typed program for the examination at least 30 days in advance. This program must follow the format posted in the "Dissertation Directives" and must be submitted to the MCW Graduate School for reproduction and distribution. It is the obligation of the student to meet all appropriate deadlines as indicated in the MCW Graduate School "Academic Calendar". Students must follow MCW Graduate School rules for dissertation defense and meet all of the requirements.

<u>There shall be a minimum of 18-month period between advancement to candidacy and dissertation defense.</u>

A public defense of the dissertation (final oral examination) is conducted after the student has completed all other formal requirements for the PhD degree and has submitted the written dissertation to his or her Dissertation Committee. Although the examination is primarily a defense of the dissertation, it will also include material relevant to the general field in which the dissertation is written, with particular attention to the more recent and significant developments in the field. Because the examination is a public defense, it must be scheduled on MU or MCW campus during weekday working hours, avoiding public or religious holidays. <u>All dissertation defenses will be held in the format of a departmental seminar.</u> The student will give a formal presentation of work followed by questions invited from all present. Immediately following the seminar, the student will meet privately with the Dissertation Committee. In this private meeting the Committee will address concerns with the oral presentation and written elements of the dissertation.

The student's Dissertation Director will inform the Chairperson of the MU-MCW BME Department of the examination outcome. The Dissertation Director will also forward this information to the MCW Graduate School in a "*Confidential Report of Completion*" along with a list of requirements within two weeks after the dissertation defense. It is assumed that the dissertation will be reviewed and edited until it meets the approval of all the committee members. However, when complete consensus seems impossible to achieve, it will be accepted if the Dissertation Director and three other committee members approve. Three copies of the completed dissertation along with a completed "*Graduate School Dissertation Completion Checklist*" form are then submitted to the MCW Graduate School.

11. Time Limitations.

All work for doctoral degrees, including the final examination, must be completed within 7 years from the initial registration in graduate courses.

V. Learning Objectives.

The Learning Objectives of BME Doctor of Philosophy training program and their outcome assessments, provide tools that ensure continuous quality improvement. Graduates earning the PhD degree will be able to:

- <u>Conduct independent research that reflects an original contribution to BME:</u> This is measured via evaluation of doctoral dissertation and defense, submission of at least one first-authored manuscript to a peer-reviewed journal, and a survey sheet that is completed by each of the Dissertation Committee members. Specifically, the following parameters are evaluated: ability to execute an appropriate research plan; research methods appropriate to the topic; conclusions and main arguments supported by the conducted research; effective use of resources to investigate the state of current knowledge relative to the research project.

- <u>Demonstrate technical proficiency in at least one area of BME:</u> This is measured via evaluation of the doctoral dissertation and defense, and a survey sheet that is completed by each of the dissertation committee members. Specifically, the following parameters are evaluated: demonstration of factual knowledge of engineering and life science; professional quality public presentation of research findings.

- <u>Recognize the need to apply ethical principles in conducting research:</u> This is also measured via evaluation of doctoral dissertation and defense, and a survey sheet that is completed by each of the Dissertation Committee members. Specifically, the following parameters are evaluated: honest reporting of results and data; proper citing in the dissertation; understanding of plagiarism; understanding of and compliance with IRB/IACUC rules and regulations

- <u>Demonstrate a commitment to professional development by participating in local and national professional development activities on a continuing basis:</u> This is measured via surveys of the Department's faculty. Specifically, the percentage of students that presented a conference abstract in the previous year is determined. Furthermore, the number of doctoral students that are members of a technical or professional society is determined and the number of students that published first-authored, peer-reviewed manuscripts is documented.

VI. Academic Dishonesty and Research Misconduct.

Upon detection of academic dishonesty, the student involved will automatically receive an "F" grade in the course. Beyond this, additional credit for graduation may be required or expulsion from the school may result depending on the nature of the offense and the decision of the Dean of MCW Graduate School according to MCW policy. Refer to the MCW Graduate School Handbook for "Definitions of Academic Dishonesty" and its consequences and to the statement regarding "Research Misconduct".

VII. Registering for Courses at MU and MCW.

Students should register at MCW for all courses they plan to take, and at MU for the courses offered at MU.

VIII. Independent Study Course BIEN 6995.

The Graduate Committee of the MU-MCW Department of BME reviews all BIEN 6995 course proposals. The proposal specifies the method for documenting successful completion of the course. Appropriate documentation is typically a summary report (with an appropriate list of references) but can also take the form of a completed project (with documentation), formal presentation, examination or other suitable evidence of accomplishment. Completion of each BIEN 6995 course must be documented by the student, approved by the course director and submitted to the Graduate Committee of the MU-MCW BME Department prior to the end of the semester in which the course is completed.

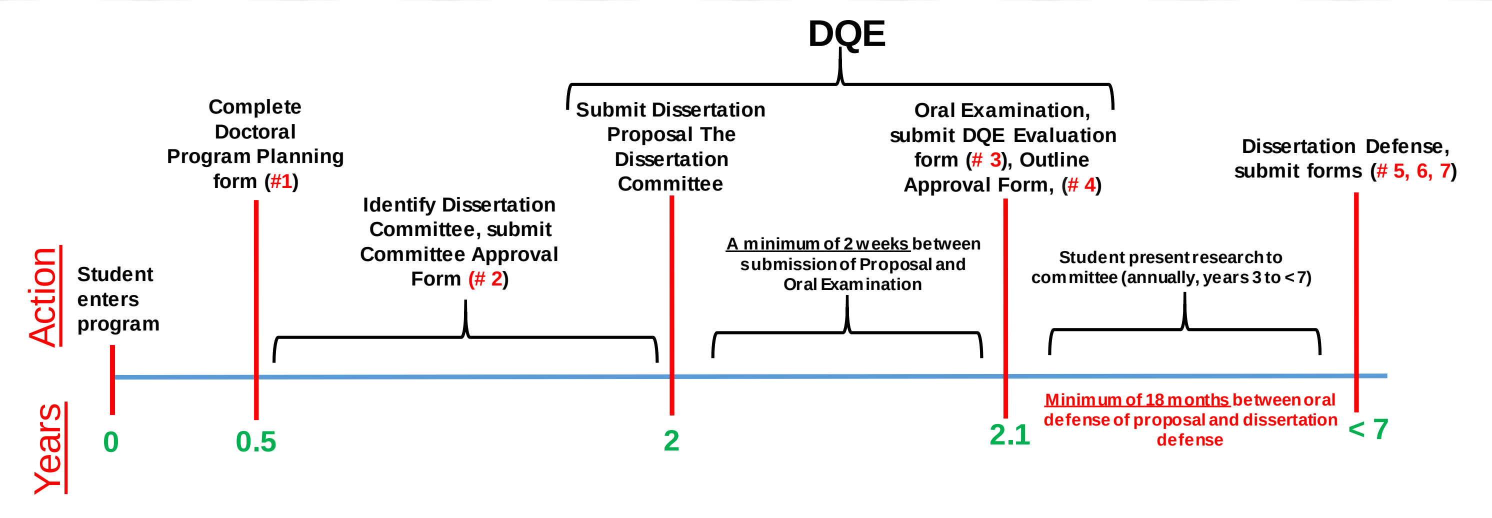
IX. Vacation and Leave Policy.

Please refer to the MCW Graduate School Handbook for more information regarding vacation and leave policy for PhD students.

X. Financial Aid.

- All **full-time** students admitted to the BME PhD program will receive continuing **tuition waiver, stipend**, and **health insurance** contingent on satisfactory progress.
- **Stipends:**
  - It is the policy of the MCW Graduate School that: (1) All full-time doctoral students in good academic standing receive a graduate stipend, and (2) that the stipend level should be uniform among all eligible students at a comparable level of training (see MCW Graduate School Handbook for more information regarding this policy).
  - Three major sources of graduate stipends:
    - **Teaching Assistantships:** Teaching assistantships provide students with a stipend for the first 18 months in the doctoral program. In return the students are expected to satisfactorily perform 20 hours of teaching-related assignments per week. **MSTP students** are not eligible for Teaching Assistantships due to the time constraints to which they must adhere (i.e. three to four years of graduate school).
    - **Research Assistantships:** Research assistantships also provide students with a stipend. In return the students are expected to satisfactorily perform 20 hours of research-related assignments per week. Research assistantships are also available from individual faculty members with research grants.
    - **Fellowships:** A limited number of fellowships (*http://www.marquette.edu/grad/*) are available through the MU Graduate School. Doctoral students are also urged to seek fellowships available from various external government institutes (e.g. NIH, AHA, NSF), foundations, and other organizations.

XI. Timeline of Doctoral Student's Progress and Milestones:



Links to main forms:

 # 1: Doctoral Program Planning Form, *https://www.marquette.edu/grad/documents/doct-prog-planning-092010.pdf*

 # 2: Dissertation Committee Approval Form
 # 3: DQE Evaluation Form
 # 4: Outline Approval Form, Dissertation Proposal
 # 5: Confidential Report of Completion
 # 6: Signature Page
 # 7: Dissertation Completion Checklist

https://infoscope.mcw.edu/Graduate-School-Intranet.htm

See ***Dissertation Completion Checklist (form # 7)*** for additional requirements for graduation.

Considerations for evaluating Readings and Research.
Criteria used to evaluate students in Readings and Research should reflect performance related to the student's effort on their dissertation or thesis project. Specifically, it is recommended that faculty mentors evaluate student effort in terms of the Core Qualities and Competencies for Graduate Education. In brief, core Qualities include: Scholarship: the pursuit of knowledge through study and research; Innovation: creativity in the generation of new knowledge; and Professionalism: conforming to the behavioral norms of a profession. Similarly, Core Competencies that students are expected to achieve during their training experience include excellence in: Knowledge and Skills, Communication, and Management, Teamwork, and Leadership.

Criteria Used to Evaluate Readings and Research.
Due to the varying nature of the research experience across different disciplines and mentors, fixed criteria for grading students are not easily established. Mentors should consider performance relative to the student's stage in the program on the following types of activities when evaluating Readings and Research:

- Written research summaries
- Presentations to the department and dissertation/thesis committee
- Motivation and commitment to research
- Data management and record keeping
- Familiarity with the literature
- Collegiality within the laboratory/group
- Ability to establish and meet pre-set deadlines and goals
- Laboratory/research skills and experimental design
- Oral and written communication skills
- Scientific honesty and integrity
- Research accomplishments and progress towards the dissertation/thesis
- Research problem solving and computing skills
- Creative thinking skills

Grading system for Readings and Research.
Student performance in Readings and Research is graded according to the following scale: E (excellent), G (good), S (substandard), and U (unsatisfactory). Please note that the definition for S has been changed from satisfactory to substandard. Examples of student activities have been provided to help clarify these grading designations:

E (excellent) – Student performance exceeds expectations. The student functions primarily independent from the mentor. For example, a student initiates and manages new collaborations related to their project, establishes a new technique for the laboratory or a new method for the research problem, submits his/her research proposal for outside funding consideration, and/or submits a manuscript for publication consideration. The student successfully troubleshoots a difficult experiment, research or computing problem independent of their mentor, or independently mentors and manages a student.

G (good) – Student performance meets expectations. The student is beginning to function independently but still requires appreciable guidance from the mentor. For example, the student actively participates in a collaboration previously established by the mentor, masters an established technique within the laboratory or problem-solving techniques, works toward initiation, preparation, or completion of their research proposal, and/or prepares a manuscript based on studies from their research project. The student successfully troubleshoots a difficult experiment/research problem with the help of the mentor or works with the mentor to successfully mentor and manage a student.

SD (substandard) – Student performance is below expectation. The student meets the bare minimum requirements established and requires substantial guidance from the mentor beyond what is expected at this point in their training. For example, the student meets deadlines but requires frequent reminders or other input from the mentor or program director. The overall product produced in the laboratory or the progress made on the dissertation/thesis needs improvement in terms of quality, efficiency, and/or timeliness. The student remains unable to successfully troubleshoot an experiment/research problem even with input from the mentor.

U (unsatisfactory) - Student performance is below minimum standards and corrective actions are required. There is a general lack of engagement by the student. The student fails to take ownership of his/her research project even after significant input from the mentor. The student fails to engage in timely communication, and overall student effort suffers from a lack of commitment to research.

Recommendation when assigning an S grade for Readings and Research – Mentors who assign an “S” in Readings and Research should plan to meet with their student to discuss the specific activities that have failed to meet expectations. Recommendations on how to improve student performance in these areas should be discussed and/or documented, and when warranted, specific milestones developed and periodically evaluated with the student to improve performance to one that meets expectations.

Policy for assigning a U grade for Readings and Research - Mentors should be aware that a "U" in Readings and Research automatically places a student on probation, and two "U" grades are grounds for dismissal from the Graduate School. Given the significance of this grade, prior to assigning a “U” the Mentor will consult with members of the Dissertation/Thesis Committee (for students that have formed a dissertation/thesis committee) and the Director of the Graduate Program for feedback on the appropriateness of the decision. If there is consensus that the student performance is evaluated as Unsatisfactory, a letter explaining the basis for this grade and detailed corrective measures and strategies shall be submitted to the Director of the Graduate Program and to the Dean of the Graduate School in Biomedical Sciences. A student who receives a second evaluation as Unsatisfactory during any subsequent semester of study will be considered for dismissal.

December 4, 2019

A non-exhaustive list of existing pertinent graduate courses:

*Course has not been offered in the past 5 years

Relevant MU graduate courses (suggested track #):

BIEN 5220. Embedded Biomedical Instrumentation. 3 cr. hrs. (Track 1)
Fundamentals of digital circuit design and analysis and the application to embedded biomedical instrumentation. Topics include microprocessor principles and programming and system design constraints for medical electronics. Laboratory provides applications of concepts introduced in class.

***BIEN 5230. Intelligent Biosystems. 3 cr. hrs. (Track 1)**
Use of emerging tools in systems biology and soft computing to explore how biosystems with highly distributed "intelligence" are designed to adapt to self- and environmentally-induced perturbations. Students obtain a basic understanding of key soft computing tools and use fuzzy expert system models. Applications to smart healthcare monitoring and future product design will be explored. Prerequisite: BIEN 4700/5700.

BIEN 5320. Biomedical Instrumentation Design. 3 cr. hrs. (Track 1)
Problems in instrumentation relating to physiological measurements in the laboratory and clinic. Electronic devices for stimulus as well as measurement of physiological quantities. Design of actual instruments. Features include mechanical design, accessory design and safety requirements.

BIEN 5400. Transport Phenomena. 3 cr. hrs. (Track 4, 5)
Applications of mass, momentum, and mechanical energy balances to biomedical fluid systems. Study of physiological phenomena with an emphasis on cardiovascular systems and blood rheology.

***BIEN 5410. Applied Finite Element Analysis. 3 cr. hrs. (Track 2)**
Introduces the finite element solution method for linear, static problems. Includes calculation of element stiffness matrices, assembly of global stiffness matrices, exposure to various finite element solution methods, and numerical integration. Emphasizes structural mechanics, and also discusses heat transfer and fluid mechanics applications in finite element analysis. Computer assignments include development of finite element code (FORTRAN or C) and also use of commercial finite element software (ANSYS and/or MARC).

BIEN 5420. Biomaterials Science and Engineering. 3 cr. hrs. (Track 2)
Designed to introduce the uses of materials in the human body for the purposes of healing, correcting deformities and restoring lost function. The science aspect of the course encompasses topics including: characterization of material properties, biocompatibility and past and current uses of materials for novel devices that are both biocompatible and functional for the life of the implanted device. Projects allow students to focus and gain knowledge in an area of biomaterials engineering in which they are interested. Prereq: MEEN 2460 or cons. of instr.

BIEN 5500. Medical Imaging Physics. 3 cr. hrs. (Track 3)
Examines how light, X-rays, radiopharmaceuticals, ultrasound, magnetic fields, and other energy probes are generated and how they interact with tissues and detectors to produce useful image contrast. Addresses practical issues such as beam generation, dose limitations, patient motion, spatial resolution and dynamic range limitations, and cost-effectiveness. Emphasizes diagnostic radiological imaging physics, including the planar X-ray, digital subtraction angiography mammography, computed tomography, nuclear medicine, ultrasound, and magnetic resonance imaging modalities.

BIEN 5510. Image Processing for the Biomedical Sciences. 3 cr. hrs. (Track 3)
Introduces biomedical image processing. Topics explored include: the human visual system, spatial sampling and digitization, image transforms, spatial filtering, Fourier analysis, image enhancement and restoration, nonlinear and adaptive filters, color image processing, geometrical operations and morphological filtering, image coding and compression image segmentation, feature extraction and object classification. Applications in diagnostic medicine, biology and biomedical research are emphasized and presented as illustrative examples.

BIEN 5600. Neural Engineering. 3 cr. hrs. (Track 6)
Basic principles of neural engineering, properties of excitable tissues, quantitative models used to examine the mechanisms of natural and artificial stimulation. Basic concepts for the design of neuroprosthetic devices for sensory, motor and therapeutic applications. Design issues including electrode type, biomaterials, tissue response to stimulating electrodes and stimulus parameters for electrical stimulation and artificial control. Examples of how engineering interfaces with neural tissue show increasing promise in the rehabilitation of individuals of neural impairment.

***BIEN 5610. Introduction to Rehabilitation Robotics. 3 cr. hrs. (Tracks 1, 6)**
Presents the fundamentals of robotics as it is applied to rehabilitation engineering. Specific topics include: the fundamentals of analysis and design of robot manipulators with examples and mini-projects taken from rehabilitation applications pertaining to robotic therapy devices and personal assistants. Additional topics include: overview of rehabilitation robotics field, human-centered design of rehabilitation robots issues and challenges, robot configurations, rigid motions and homogeneous transformations, Denavit-Hartenberg representation, robot kinematics, and inverse kinematics, Euler-Lagrange equations, trajectory generation, sensors, actuators, independent joint control, force control and safety.

***BIEN 5620. Rehabilitation Engineering: Tele rehabilitation Research Tools. 3 cr. hrs. (Tracks 1, 6)**
Introduces rehabilitation science as the study of tissue and functional change, including: overview of key human sensory modalities and neuromotor systems in the context of functional capabilities and human performance metrics; review of spontaneous recovery mechanisms in response to various types of tissue trauma; review of roles of genetics and gene transcription networks in pathology and functional recovery prognosis; and the concept of rehabilitative assessment and therapeutic interventions as an optimization problem. Also focuses on the use of assistive technology to enhance access to independent living and to optimize the delivery of rehabilitative healthcare services. Includes rehabilitation biomechanics of physical interfaces, use of access and usability engineering in product design and innovative assessment and intervention strategies for neurorehabilitation.

***BIEN 5630. Rehabilitation Engineering: Prosthetics, Orthotics, Seating and Positioning. 3 cr. hrs. (Track 6)**
Presents an overview of biomedical engineering as it applies to rehabilitation engineering, specifically, the design and prescription of prosthetic limbs, orthotic devices, and seating and positioning systems. Topics include: medical terminology, musculoskeletal anatomy, muscle mechanics, soft tissue mechanics, gait/locomotion, amputation surgery, lower extremity prosthetics, lower extremity orthotics, hand function, electromyography, upper extremity prosthetics, upper extremity orthotics, seating and positioning, and assistive devices. *Marquette University - Graduate School Bulletin* 141

***BIEN 5640. Bioengineering of Living Actuators. 3 cr. hrs. (Tracks 5, 6)**
Overview of muscle tissue as a living actuator from the perspective of engineering design, systems biology, muscle modeling and adaptive control. Prerequisite: BIEN 4700/5700.

BIEN 5700. Systems Physiology. 3 cr. hrs. (All Tracks)
Analyses of the underlying physiologic and bioengineering aspects of the major cell and organ systems of the human from an engineer's point of view. Classic physiologic approaches used to introduce topics including cell functions, nervous system, nerve, muscle, heart, circulation, respiratory system, kidney, reproduction and biomechanics. Design problems including models of cell-organ-system function and problems in biomechanics illuminate topics covered. Computer techniques and relevant instrumentation are incorporated. Experts on related topics are invited to speak as they are available.

BIEN 5710. Analysis of Physiological Models. 3 cr. hrs. (Tracks 4, 5)
Development of continuous (compartmental) and distributed-in-space-and-time mathematical models of physiological systems and molecular events. Analytical and numerical methods for solving differential equations of the initial and boundary value types. Simulation of model response, and estimation of model parameters using linear and nonlinear regression analysis.

***BIEN 5720. Cardiopulmonary Mechanics. 3 cr. hrs. (Tracks 4, 5)**
Examination of the physiological behavior of the cardiovascular and pulmonary systems from an engineering perspective. Emphasis is on understanding the mechanical basis of physiologic phenomena via experimental models.

BIEN 5931. Topics in Biomedical Engineering. 1-3 cr. hrs. (All Tracks)
Course content announced prior to each term. Students may enroll in the course more than once as subject matter changes. Possible topics include biomechanics, experimental methods, neuroanatomy, telemetry, etc.

BIEN 6120. Introduction to the Finite Element Method. 3 cr. hrs. (Tracks 5, 6)
Introduces finite element analysis as applied to linear, static problems. Application to problems in plane strain, plane stress, and axisymmetry. Development of shape functions and element stiffness matrices. Although primarily structural analysis, also considers problems in heat transfer and fluid mechanics. Use of user-written and packaged software. Prerequisite: CEEN 2130 or MEEN 2130; and matrix/linear algebra or equiv.

***BIEN 6121. Applied Finite Element Analysis and Modeling. 3 cr. hrs. (Tracks 5, 6)**
Advanced finite element analysis as applied to nonlinear (both material and geometric nonlinearities), dynamic problems. Use of penalty methods and perturbed Lagrangian methods. Use of user-written and packaged software. Critical reviews of finite element analysis in biomechanical research. Prerequisite: BIEN 6120; or CEEN 6120 or equiv.

BIEN 6200. Biomedical Signal Processing. 3 cr. hrs. (All Tracks)
Introduces students to statistical processing of biomedical data. Topics include: data acquisition, probability and estimation, signal averaging, power spectrum analysis, windowing, digital filters and data compression. Students complete several computer projects which apply these processing methods to physiologic signals. Prerequisite: MATH 2451; and proficiency in C or FORTRAN.

BIEN 6210. Advanced Biomedical Signal Processing. 3 cr. hrs. (All Tracks)
Covers modern methods of signal processing encountered in the bio-medical field including parametric modeling, modern spectral estimation, multivariate analysis, adaptive signal processing, decimation/interpolation, and two-dimensional signal analysis. Students complete several computer projects which apply these modern techniques to physiologic data. Prerequisite: BIEN 6200 or equiv.; knowledge of C or FORTRAN.

***BIEN 6220. Multidimensional Biomedical Time Series Analysis. 3 cr. hrs. (Tracks 3, 5)**
Theory and implementation of methods used to collect, model and analyze multidimensional time series encountered in biomedical applications such as functional imaging, electrophysiologic mapping and the study of physiologic control systems. Prerequisite: BIEN 6200; proficiency in C or FORTRAN.

***BIEN 6300. Biomedical Instrumentation. 3 cr. hrs. (Track 1)**
Explores relationships between instruments for physiologic measurement and monitoring with living systems. Physiologic signals, noise, and available sensors and transducers and their characteristics are discussed from time and frequency domain points of view.

Systems topics include various new and conventional medical instrumentation. Other topics include clinical and new clinical laboratory instrumentation, instrumentation for research, artificial organs and prostheses. Includes the use of scientific literature, literature searches, design projects, computer projects. Prerequisite: BIEN 5700; or BIEN 5320; and high level computer language or equiv.

***BIEN 6310. Microprocessor Based Biomedical Instrumentation. 3 cr. hrs. (Track 1)**
Discusses the application of microprocessors, microcontrollers, and digital signal processors to biomedical instrumentation. Complements BIEN 6300, which covers transducers, sensors, analog signal conditioning, and analog to digital conversion. Emphasizes evaluating the memory, power, resolution, cost, and computational requirements of a particular application, and then selecting a type (microprocessor, microcontroller, or digital signal processor) and particular model of processor to satisfy the system requirements. Students design at least two complete processor based systems. Prerequisite: Knowledge of digital electronics and microprocessors.

***BIEN 6320. Radio Frequency Applications in Biomedical Engineering. 3 cr. hrs. (Track 1)**
Radio frequency design and applications for biomedical engineering and medicine. Circuit elements, equivalent circuits, impedance transformations, Smith Chart, two ports, scattering parameters, amplifiers, resonant circuits, mixers, receivers. Applications include telemetry, transcutaneous power transfer, hyperthermia, rf ablation, magnetic resonance imaging; HP-EESOF LIBRA and Ascent CAD are introduced as analysis and design tools. Guest speakers. Written and oral design reports. Prerequisite: Undergraduate background in circuit theory and analog electronics.

BIEN 6391 Special Topics: Advanced Systems Physiology for Biomedical Engineers. 3 cr. hrs. (All Tracks)
This course takes a disease-based approach to understanding systems physiology when those systems go wrong. Examples will be taken from diseases of the cardiovascular, respiratory, endocrine and immune systems. Course material will span systems ranging from cellular and molecular to whole organ and organism. Students will work in teams to develop disease-based models that capture the multiscale, complex behavior underlying human disease.

***BIEN 6400. Biofluid Mechanics. 3 cr. hrs. (Tracks 4, 5)**
Development of the theory of fluid mechanics as applied to living systems. Considers both steady and unsteady flows of Newtonian and non-Newtonian fluids. Topics include: viscometry, blood flow, gas and aerosol flows, pulsatile flow and wave propagation and applications to the understanding of flows in organs and to the measurement of blood pressure and flow. Prerequisite: BIEN 4400 or equiv.; or MEEN 3320 or CEEN 3150.

***BIEN 6410. Biological Mass Transfer. 3 cr. hrs. (Tracks 4, 5)**
Development of the theory of mass transfer. Fick's law and free diffusion. Osmosis, facilitated diffusion, active transport, transport across cell membranes and applications to cell biology and organ physiology.

***BIEN 6420. Biomechanical and Biomaterial Systems Analysis. 3 cr. hrs. (Track 2)**
Using fundamentals of biomaterials engineering and biocompatibility, analyzes the functions that organs serve and to analyze the efficacy and safety of artificial organs systems. Some organs/tissues discussed include the kidneys, liver, skeleton, skin, heart, muscles, eyes, and ears. Critically examines the suitability of state-of-the-art artificial organ systems, including artificial hearts, orthopaedic prostheses, kidney dialyzers, and cochlear devices to fulfill the functions of the replaced organs/tissues. Prerequisite: BIEN 5420.

BIEN 6440. Biomedical Engineering Analysis of Trauma. 3 cr. hrs. (Track 2)
An engineering analysis of the physiological changes following impact to the head, spinal cord, and limbs, and electrical events and effects on tissues are treated.

BIEN 6450. Musculoskeletal Biomechanics 1. 3 cr. hrs. (Track 2)
Emphasizes the interrelationship of force and motion as related to anatomic structure and function. Examines the forces and motions acting in the skeletal system and the various techniques used to describe them. Highlights current concepts as revealed in the recent scientific and engineering literature. Topics include: bone mechanics, joint mechanics, gait kinematics, instrumentation and measurement of biomechanical phenomena, and computer modeling of the musculoskeletal system. Prerequisite: MEEN 2120 or CEEN 2120 and MEEN 2130 or CEEN 2130.

BIEN 6451. Musculoskeletal Biomechanics 2. 3 cr. hrs. (Track 2)
Advanced concepts of kinematics and mechanics as they apply to the fields of biomechanics and rehabilitation. Covers aspects of gait, bone and joint surgery, and soft tissue surgery. Detailed study of joint mechanics, implant applications and mobility device function is performed. Includes advanced analysis and modeling as well as laboratory-based final project. Prerequisite: BIEN 6450.

***BIEN 6470. Biomechanics of the Spine. 3 cr. hrs. (Track 2)**
Analyzes anatomical and functional relationships among the hard and soft tissue structures of the spine as a function of vertebral column development, aging, disease and trauma. Emphasis given to the mechanisms of external and internal load transfer. Imaging (e.g. CT), experimental and finite element methods are used to study the effects of physiologic/traumatic loading, surgery and spinal disorders. Discusses current advancements in biomechanical/clinical literature.

BIEN 6500. Mathematics of Medical Imaging. 3 cr. hrs. (Track 3)
Begins with an overview of the application of linear systems theory to radiographic imaging (pinhole imaging, transmission and emission tomography), and covers the mathematics of computed tomography including the analytic theory of reconstructing from projections and extensions to emission computed tomography and magnetic resonance imaging. Topics may also include three-dimensional imaging, noise analysis and image quality, and optimization. Contains advanced mathematical content.

BIEN 6600. Neuromotor Control. 3 cr. hrs. (Tracks 2, 6)
Overview of current issues in neuromotor control and movement biomechanics. Special emphasis on the study of normal and impaired human movement. Topics include: muscle mechanics, biomechanics of movement, neural circuitry, strategies for the neural control of movement (including a discussion of adaptation and motor learning) and potential applications of biomedical engineering techniques to the study and improvement of impaired motor function. Prerequisite: BIEN 3300 which may be taken concurrently or equiv.; or cons. of instr.

BIEN 6610. Rehabilitative Biosystems. 3 cr. hrs. (Tracks 5, 6)
Examines the plastic changes in biological systems that occur in response to targeted stimuli. These processes involve responses by cells to chemical, mechanical, or electrical stimuli (which may be related), which may be influenced or directed using engineering techniques. Examines the homeostasis of physiologic systems and their response to pathologic and rehabilitative stimuli. Examines engineering applications involving the diagnosis and rehabilitation of musculoskeletal, neurologic and cardiopulmonary biosystems in the context of the underlying cellular mechanisms. Prerequisite: BIEN 5700which may be taken concurrently; and PHYS 1004.

BIEN 6620. Modeling Rehabilitative Biosystems. 3 cr. hrs. (Tracks 5, 6)
Introduction to large-scale mathematical models of various physiological systems of interest in rehabilitation (e.g., cardiovascular, pulmonary, musculoskeletal, etc.). Discusses mathematical modeling, a widely used tool for testing hypotheses regarding the underlying mechanisms of complex systems such as physiological systems in health, disease and recovery. For each, simulation is used to further our understanding of the adaptive processes of these systems in response to physiological/pathophysiological stresses and rehabilitative interventions. Prerequisite: BIEN 5710 and BIEN 5700.

BIEN 6710. Cellular and Molecular Bioengineering. 3 cr. hrs. (Track 4)
Main topics include: cellular biomechanics with an emphasis on the cardiovascular system, molecular bioengineering, biotransport phenomena, and tissue engineering with focus on artificial internal organs. Cellular biomechanics topics covered are biomechanics of the endothelium, endothelial-immune cell interactions, and blood cell structural biomechanics. Topics in molecular bioengineering include chemotaxis and chemokinesis, and modeling of receptor-mediated endocytosis. Biotransport and tissue engineering topics include bioreactor design and the analysis and development of artificial internal organs like the liver and pancreas.

BIEN 6931. Topics in Biomedical Engineering. 3 cr. hrs. (All Tracks)
Subject matter variable as determined by needs of biomedical graduate students. Students may enroll more than once as the subject matter changes. Possible topics: biostatistics, experimental methods, neuro-anatomy, optics, etc.

***BIEN 6932. Advanced Topics in Biomedical Engineering. 3 cr. hrs. (All Tracks)**
Advanced topics in design and analysis of biomedical instruments, devices and interfaces. Project approach drawing from current literature and current projects of laboratories of affiliated institutions. Topics include bioelectronics, biomechanics, biomaterials, and rehabilitation engineering.

BIEN 6953. Seminar in Biomedical Engineering. 1 cr. hrs. (All Tracks)
Scholarly presentations on current topics in biomedical engineering and related areas by visiting professors, resident faculty and graduate students. Attendance is required of all full-time graduate students. SNC/UNC grade assessment. Mandatory for all full-time BIEN graduate students.

***BIEN 6954. Seminar in Biomedical Computing. 1 cr. hrs. (All Tracks)**
Scholarly presentations on current topics in biomedical engineering and related areas by visiting professors, resident faculty and graduate students. Attendance is required of all full-time graduate students. SNC/UNC grade assessment. Mandatory for all full-time BIEN graduate students.

BIEN 6995. Independent Study in Biomedical Engineering. 1-3 cr. hrs. (All Tracks)
Prerequisite: Cons. of instr. and cons. of dept. ch.

***BIEN 8110. Research Methodologies 1. 3 cr. hrs. (All Tracks)**
Development of research aims and hypotheses, identification of relevant scientific literature, experimental approaches, statistical design, and pilot work to obtain preliminary results. Emphasizes written communication of research theme. The course project consists of the development of a research proposal including research aims, background, pilot experiments, and experimental design and methodology. Prerequisite: Accepted Ph.D. student in biomedical engineering.

***BIEN 8120. Research Methodologies 2. 3 cr. hrs. (All Tracks)**
Oral and written communication of research results including graphics and text. Addresses graphical presentation of data and conceptual development of a scientific presentation and a manuscript. Emphasizes the basics of clear and effective scientific communication. Work culminates in the development of a scientific manuscript for peer review. Prerequisite: Accepted Ph.D. student in biomedical engineering.

***BIEN 8210. Teaching Methodologies. 3 cr. hrs. (All Tracks)**
Seminar aimed at issues important for teaching in a university setting. Topics include: development of teaching philosophy, planning a class, designing a syllabus, assessing student learning and using technology in the classroom. Taught in conjunction with the Preparing Future Faculty (PFF) program. Prerequisite: Accepted Ph.D. student in biomedical engineering.

BIEN 8995. Independent Study in Biomedical Engineering. 1-3 cr. hrs. (All Tracks)
In-depth research on a topic or subject matter usually not offered in the established curriculum with faculty and independent of the classroom setting. Prerequisite: Cons. of instr. and cons. of dept. chair.

BIOL 5703. Exercise Physiology. 3 cr. hrs. (All Tracks)
Study of the effects of acute and chronic exercise on selected organ systems. Particular emphasis will be placed on muscle, cardiovascular, respiratory, and environmental physiology.

EECE 6010. Advanced Engineering Mathematics. 3 cr. hrs. (All Tracks)
Prerequisite: MATH 2451 or equivalent and proficiency in computer programming. Linear algebra and matrix theory, ordinary differential equations, partial differential equations, and complex variables emphasizing both theoretical and numerical aspects as well as engineering applications.

MSCS 5720. Statistical Methods. 3 cr. hrs. (All Tracks)
Probability, discrete and continuous distributions. Treatment of data, point and interval estimation, hypothesis testing. Large and small sample method, regression, non-parametric methods. An introduction to the basic understanding of statistical methods. Applications-oriented.

MSCS 5740. Biostatistical Methods and Models. 3 cr. hrs. (All Tracks)
Introduction to the statistics of life science and the use of mathematical models in biology. Data analysis and presentation, regression, analysis of variance, correlation, parameter estimation and curve fitting. Biological sequence analysis, discrete and continuous mathematical models and simulation.

MEEN 6101. Advanced Engineering Analysis I. 3 cr. hrs. (All Tracks)
Matrices and linear algebra with applications. Tensor analysis and applications. Calculus of variation. Green's function techniques. Complex variable theory and applications. Topics in ordinary and partial differential equations.

Relevant MCW graduate courses (suggested track #)

Interdisciplinary Doctoral Programs in Biomedical Sciences

16215, 16216, 16217, 16218. Foundations in Biomedical Sciences I-IV. 3 credits each. (Tracks 4, 5, 6)
Foundations in Biomedical Sciences (FBS) is broken into 4 course modules and represents the bulk of the didactic core coursework for first year IDP students. Each course module presents students with integrated and immersive cellular/molecular and systems/physiological level course material. This challenging, high-paced set of courses engage students in the major research interests and teaching philosophies of the participating departments which helps prepare students with a strong foundation for their journey into their elective courses that will ultimately guide their PhD dissertation work.

16242. Techniques in Molecular and Cellular Biology. 2 credits. (Tracks 4, 5, 6)
The objective for the Techniques course is to provide a theoretical and practical foundation underlying a number of the most common experimental techniques required for biomedical research. The information presented in this course will introduce procedures and experimental strategies that are commonly used in biomedical research projects and will facilitate students' comprehension of the scientific literature even if they don't use the techniques in their own research. The lecture materials present the theory behind each technique, the practical limitations of each techniques, and the types of questions that each technique addresses, with emphasis on how each can be applied to generate new insight into biomedical research questions.

16290 & 16291. Professional Development 1 and 2. 1 credit each. (All tracks)
This course is taken in the fall and spring semesters of the first year and incorporates a multifaceted approach to introduce students to important elements of Professional Development. The course will incorporate lectures, active learning, and team-based approaches to such topics as preparing a laboratory notebook, scientific writing and reviewing, how to structure an effective hypothesis, research ethics, formulating an individual development plan, and presentation skills. Students will also participate in Responsible Conduct in Research training activities and engage in peer review discussions of the four laboratory rotation reports.

16292. Writing a Scientific Paper. 1 credit. (All tracks)
This course will present a step-by-step approach to putting together a scientific paper. Students will be divided into groups of 3, and these groups will stay together for the duration of the course. Each group will be given an identical set of data with which to compose a manuscript. Each week, a different aspect of paper writing will be discussed, and students will be given a take home assignment to write that particular component of the paper within the small groups. In the final week of the class, the finished papers will be peer reviewed by two other groups and a member of the faculty. The course will be graded on attendance, successful and timely completion of the assignments and evaluation of the final manuscript.

16xxx. Writing an Individual Fellowship. 1 credit. (All tracks)
This course provides a systematic approach towards writing a F31-like individual research fellowship. Topics include the organization of the NIH, how the NIH invites investigators to submit applications to support their doctoral studies, how PhD trainees and their mentors respond to these invitations, and how the NIH reviews a fellowship application. A weekly didactic session will be presented to the entire group of students who will have weekly individual writing assignments to complete and will have a weekly small group session to share their progress towards the completion of their writing assignments. Each student will identify a mentor-approved research topic that will be developed into a fellowship proposal, emphasizing the writing of a Summary, Specific Aims Page, and Research Plan as outlined in PA-19-195 and SF-424(F). Writing a Scientific Paper (16292) is a prerequisite for this course.

16271. Fundamentals of Neuroscience. 3.5 credits. (Tracks 4, 5, 6)
Fundamentals of Neuroscience follows a multidisciplinary approach to current knowledge about the structural and functional properties of the nervous system. The mechanisms of the nervous system are described at the molecular, cellular, systems and complex brain

function levels. The course includes in-class lectures, seminars from prominent scientists (video archives), and written assignments. The purpose of this course is to introduce 1st year graduate students to the structure and function of the human nervous system.

16272. Graduate Neuroanatomy. 0.5 credits. (Tracks 4, 5, 6)
Graduate Neuroanatomy is a lab-based course intended to accompany MCW course Fundamentals of Neuroscience. The purpose of this course is to introduce 1st year PhD students to the anatomy of the human nervous system.

16265. Organ Systems Physiology. 2 credits. (All tracks)
Organ Systems Physiology is a first year elective course that focuses on the classic topics in physiology – the science of regulation and control systems – including the Physiology of Cells, Muscle, Cardiovascular, Pulmonary, Renal, GI, Endocrine, and Reproduction. It will also introduce the students to animal models in physiological research appropriate for the topic at hand. It will follow and build on the planned new first year first semester Graduate School course that will run from August-February. The course will be comprised of (1) interactive lectures by Dr. Raff and (2) Journal Club in which the students will present and discuss journal articles using animal models in physiology. The course will meet twice a week (1.5 hrs/session; 3 hrs/week) for a total of 12 weeks.

16275. Understanding Cell Signaling through Therapeutic Drugs. 2 credits. (Tracks 4, 5, 6)
This course will present advanced concepts in cellular signaling by analyzing the molecular mechanisms responsible for the therapeutic benefit, unanticipated toxicity, and limited effectiveness of particularly well-known drugs that target specific signal transduction pathways. The topics are designed to promote an enhanced understanding of the complexities of multiple signaling pathways, and a sophisticated appreciation of how these pathways are integrated to produce cellular responses. The course has a translational emphasis by focusing on the multiple molecular actions of current FDA-approved drugs, as well as discontinued drugs that were removed from the market due to unanticipated toxicity or limited effectiveness. The lectures will provide an advanced analysis of the molecular responses that led to the success or failure of these drugs, encouraging students to develop sophisticated analytical skills that will allow them to define how different signaling pathways are integrated. Lectures presented by the instructors will provide an in-depth overview of different signaling pathways, and manuscript discussions will promote additional advanced analysis that will creatively engage the students.

Neurosciences Doctoral Program

12206 Integrated Neuroscience. 4 credits. (Tracks 4, 5, 6)
This course follows a multidisciplinary approach to current knowledge about the structural and functional properties of the nervous system. The mechanisms of the nervous system are described at the molecular, cellular, and multi-cellular levels. The course includes both lectures and laboratory sessions.

12210 Fundamentals of Neuroscience. 4 credits. (Tracks 4, 5, 6)
This course follows a multidisciplinary approach to current knowledge about the structural and functional properties of the nervous system. The mechanisms of the nervous system are described at the molecular, cellular, and multi-cellular levels. The course includes both lectures and laboratory sessions. The purpose of this course is to introduce PhD students to the anatomy and function of the human nervous system.

12221 Advanced Systems Neuroscience. 3 credits. (Tracks 4, 5, 6)
This course covers seven selected areas in systems neuroscience, including: neuronal information processing and control systems, cerebral hemodynamics, metabolism and neuronal activity, sensory systems, motor systems, attentional systems, learning and memory and motivational systems. Some lectures introducing fundamental concepts and current research topics are presented but learning occurs primarily through readings and discussions. Prerequisite:12206 or consent of the course director.

12237 Cellular and Molecular Neurobiology. 3 credits. (Tracks 4, 5, 6)
Readings and discussion in cellular, molecular, and developmental neurobiology. Among the topics covered in this course are ion channels and the ionic basis of potentials; mechanisms of synaptic transmission; neurotransmitter receptors and their receptors; sensory signal transduction and neural development. Prerequisite: 12206 or consent of the course director.

Biochemistry Doctoral Program

02203 Molecules to Cells. *5 credits.* **(Tracks 4, 5, 6)**
Molecules to Cells is designed to provide students with integrated concepts of biochemistry, medical genetics, human development and cell and tissue biology. The goal of the curriculum is for students to become aware of the contributions these disciplines bring to future developments in clinical diagnosis and treatment. Molecules to Cells will expose students to the molecular and chemical principles of life from the structure and function of DNA and proteins, to metabolism, membrane transport and cellular recognition. The course provides the basic science foundation in the principles and concepts of genetics that is required for the understanding of the rapidly changing clinical practice of medical and translational research.

02207 Enzyme Kinetics and Receptor Binding: Theory and Practice. *1 credit.* **(Tracks 4, 5, 6)**
This course teaches both the theoretical framework and practical aspects of enzyme kinetics and receptor binding studies. Topics covered include basic steady state kinetics including the determination and meaning of Km and Vmax values for simple and multi-substrate reactions, determination binding properties and kinetic consequences of common reversible inhibitors (competitive, non-competitive, uncompetitive, mixed), slow-on, slow-off inhibitors and irreversible inactivators. Dissociation constants and procedures for determining them will be discussed for both enzymes and macromolecular receptors. Practical methodologies for determining pre-steady state kinetics will be presented. Practical aspects of designing kinetic studies will be discussed and later sessions of the course will involve reading and student-led discussions of studies in the literature that illustrate ways in which studies of enzyme kinetics or receptor binding advanced the study of particular enzymes and other macromolecules. Over the six-week duration of the course each

student will prepare a short report in which he or she describes the design and, if possible, execution of a series of kinetic or receptor binding studies that draw on the teachings of the course and are related to the work each proposes to carry out for a dissertation.

02-16274 Metabolism. *1 credit. Prerequisite: Completion of IDP course curriculum.* **(Tracks 4, 5, 6)**
This new elective course will be a didactic based course that will comprehensively review subjects important to metabolism. The topics covered will range from carbohydrate metabolism to oxidative phosphorylation to lipid and amino acid metabolism. There will be a strong focus of these topics in health and disease, especially as they relate to the cardiovascular system, cancer, diabetes and immune system function. The depth of coverage within each topic will not necessarily be comprehensive, but there may be a few aspects of each topic that will be highlighted by focusing on landmark studies or recent developments from published research articles.

Biophysics Doctoral Program

03220 Introduction to Magnetic Resonance. 3 credits. (Track 3)
The course provides basic knowledge for students who will continue to study ESR or NMR. The material covers magnetic resonance of the hydrogen and helium atoms, NMR spectra in liquids, basic ESR of radicals in solution, trapped radicals in solids, triplet states, spin relaxation, molecular rate processes, and double resonance. An understanding of matrix elements, eigenvalues, angular momentum, and tensor vector is recommended.

03223 Electron Spin Resonance. 3 credits. (Tracks 3, 4)
The aim of the course is to provide an introduction to the theory and practical applications of modern electron spin resonance (ESR) spectroscopy. Basic ESR theory, biological free radical spectroscopy, relaxation and motional phenomena, spin labeling and transition metal ESR are among the topics covered.

03226 Biophysical Techniques in Biochemistry. 3 credits. (Tracks 4, 6)
This course will introduce the basic theory and practical applications of an array of biophysical techniques commonly used in biochemical research. Optical and magnetic spectroscopies, X-ray crystallography and kinetics techniques are a sampling of the topics covered in this comprehensive course.

03230 Nuclear Magnetic Resonance. 3 credits. (Track 3)
This course is designed as an introduction to nuclear magnetic resonance (NMR) and nuclear magnetic resonance imaging (MRI). Emphasis will be given to theory and application of modern MRI techniques.

03238 Magnetic Resonance Imaging. 3 credits. (Track 3)
This is a course on the physics of modern MRI. It will take a classical approach to spin physics and will focus on pulse sequences, K-space analysis and hardware. An understanding of calculus is required, and Fourier analysis is recommended.

03239 Functional MRI Contrast Mechanisms and Applications. 3 credits. (Track 3)
The use of magnetic resonance imaging (MRI) to evaluate tissue function will be described. The course will be dedicated to discussing functional MRI (fMRI) methods that use both endogenous contrast (labeled water, deoxygenated blood) and exogenous (injectable) MR contrast agents to image tissue function. The theory and physiology necessary for understanding the MR contrast mechanisms, together with the practical knowledge necessary for performing the MR experiments, will be discussed. Demonstrations of functional MRI experiments will be included. Prerequisite: 03238.

03240 Fourier Transforms. 3 credits. (Tracks 4, 5)
Material covers theory of Fourier transforms, digital transforms, nuclear magnetic resonance images, reconstruction, pulse spectroscopy methods, and electrical signal processing. An understanding of calculus and tensor vectors is recommended

03251 Free Radicals in Biology. 3 credits. (Tracks 4, 5, 6)
Topics to be discussed include: the nature of free radicals; radical initiation, propagation, termination; free radical reactions of biological interest; and the role of free radicals in physiological and pathological processes.

03254 Advanced X-Ray Crystallography. 3 credits. (Track 3)
The student will receive both didactic lectures on the physics of X-ray diffraction, diffraction symmetry, reciprocal space, crystals and their diffraction properties; and calculations related to the actual solution of a crystal structure. All students will make extensive use of a computer in the laboratory exercises leading to the total solution of a crystal structure for a biologically active molecule composed of 20-30 atoms. Heavy atom and probability-based structure solutions will be explored.

Physiology Doctoral Program

08204 General Human Physiology. 4 credits. (All Tracks)
Basic functions of cells, tissues and organ systems are presented with homeostasis and physiological reserve as the central emphasis. Regulatory mechanisms which govern the performance of each physiological system are covered, as are the limits of performance of these systems. The course includes lectures and small group interactive discussions with the lecturing faculties: Drs. Cowley, Greene, Forster, Mattson, and Lombard.

08230 Physiological Genomics. 5 credits. (Track 4)
This course is directed by Dr. Geurt and taught by many MCW faculties is a combination lecture and discussion course on the theory and methods of elucidating gene function. Specifically, this course covers topics in Physiological Genomics at an advanced level emphasizing the tools and techniques that are available to investigators exploring the relationship between genotype and phenotype. Material are selected to emphasize high throughput screening and Bioinformatics techniques. Specific examples of

applications of physiological genomics to important research problems will be discussed. Students will acquire the expertise required to develop a research proposal and will participate in a mock study section to witness the process by which grants are reviewed.

08284 Computational Methods for Biomedical Research. 3 credits. (Tracks 2, 4, 5)
This course taught by Dr. Dash focuses on practical techniques for simulation and analysis of biological systems, developed largely through application-driven examples. Examples will be developed to a depth at which models will be used to analyze real biological or physiological data. To accomplish this, the important details of the underlying biological systems must be described along with a complete step-by-step development of model assumptions, the resulting equations, and (when necessary) computer code.

08285 Mathematical Biology. 3 credits. (Tracks 2, 4, 5)
Dr. Dash teaches the students how to express physiological problems in equations and how to solve such equations. Emphasis on physiological problem solving methods rather than mathematical theory. Topics include the application of matrices, differential equations, and numerical analysis to problems in bioelectricity, biomechanics, and optics.

Pharmacology and Toxicology Doctoral Program

07201 General Pharmacology. 4 credits. (Tracks 4, 5, 6)
The course consists of lectures and demonstrations on the principles of pharmacology and the major therapeutic drugs. Discussed are the interaction of drugs, drug absorption and elimination, drug distribution, dose response relationships, toxicity, and therapeutic efficacy.

07202 Survey of Pharmacology. 3 credits. (Tracks 4, 5, 6)
Primarily for graduate students who need an introduction to the basic concepts of pharmacology and a working knowledge of the mechanisms of action of major classes of drugs.

07224 Cellular Signal Transduction. 3 credits. (Tracks 4, 5, 6)
This course provides an in-depth presentation of mechanisms of cellular signaling at a level designed for doctoral students in the biomedical sciences. The emphasis is on receptors, second messenger systems, G proteins and signal transduction.

07225 Ion Channels and Signal Transduction. 3 credits. (Tracks 4, 5, 6)
This course provides discussion of the function of ion channels in mammalian cells. The course provides in-depths on ion channel structure, function and regulation.

Cell Biology, Neurobiology and Anatomy Doctoral Program

31153 Cell Tissue Biology. 4 credits. (Tracks 4, 6)
Structural and functional organization of specific cells and subcellular components, tissues, and organs is presented. The student must learn to identify and describe microscopic structures and to understand their functional relationships with other tissues and organs.

31207 Introduction to Neuroscience. 2 credits. (Tracks 4, 6)
This course provides an introduction to the neurosciences. A brief but integrated overview of neuroanatomy, neurophysiology and neurochemistry will be provided. The course consists of both lectures and laboratory exercises.

31212 Developmental and Stem Cell Biology. 3 credits. (Tracks 4, 6)
The offered course provides a detailed introduction to Developmental and Stem Cell Biology. The course uses a lecture-style format supplemented with paper discussions. The intent of the course is to provide a solid academic background in developmental biology to graduate students embarking upon research into cell differentiation and development.

31250 Advanced Cell Biology. 3 credits. (Tracks 4, 6)
Lectures and readings in the renewal, differentiation, communication, adhesion, secretion, motility, gene activity, and mitochondrial dynamics of eukaryotic cells.

Biostatistics Doctoral Program

04200 Biostatistics I. 3 credits. (All Tracks) (offered every fall)
This is an introductory course in biostatistical methods for non-biostatistics majors. Topics include elementary probability, sampling, point and interval estimation and hypothesis testing.

04224 Biostatistical Computing. 3 credits. (All Tracks) (offered every fall)
This course will cover the details of manipulating and transforming data required for statistical analysis, such as reshaping the data from a per case to a per event within a case and vice-versa. It will also cover the techniques necessary to write functions and macros in both SAS and S-Plus for developing new/modified data analysis methods. Students are expected to be facile in the use of computers before they take this course. Admission is only by consent of instructor.

04231 Statistical Models and Methods I. 3 credits. (All Tracks) (offered every fall)
Models and analyses for count data and contingency tables, basic nonparametric methods including sign, rank-sum and signed-rank tests, simple linear regression model and inference, checking model assumptions, correlation analysis, one-way and two-way analysis of variance. Emphasis is on models, their application to data and interpretation.

04232 Statistical Models and Methods II. 3 credits. (All Tracks) (offered every spring)

Factorial, nested, split-plot and repeated measures designs, multiple regression and variable selection, multiple comparisons, logistic regression, discriminant analysis, principal components and factor analysis, rates and proportions, introduction to survival analysis.

04233 Statistical Models and Methods III. 3 credits. (All Tracks) (fall, every other year)
Model diagnostics in regression analysis, influence and leverage, outliers, collinearity, remedies including transformations and ridge regression; Models for discrete data, two-way and multi-way tables, loglinear models, analysis of loglinear models, Mantel-Haenszel test, models for ordinal variables, multinomial response and matched pairs, analysis of repeated response data.

04285 Introduction to Bayesian Analysis. 3 credits. (All Tracks) (spring, every other year)
This course introduces basic concepts and computational tools for Bayesian statistical methods. Topics covered include one and two sample inference, regression models and comparison of several populations with normal, dichotomous and count data.

04363 Advanced Statistics I. 3 credits. (All Tracks) (spring, every other year)
Exponential family of distributions: likelihood, score, information, mle; asymptotic related to likelihood, Wald, Score, and Likelihood Ratio statistics, delta method; types of likelihoods, e.g. marginal, conditional and profile likelihood; generalized estimating equations and quasi-likelihood; multiple comparisons.

04365 Linear Models I. 3 credits. (All Tracks) (fall, every other year)
Review of matrix algebra and vector spaces, multivariate normal distribution and quadratic forms, least squares estimation, testing nested models, weighted least squares, one-way ANOVA, testing contrasts, multiple comparison, partial and multiple correlation coefficients, polynomial regression, lack-of-fit tests.

04384 Statistical Genetics. 3 credits. (All Tracks) (spring, every other year)
Fundamental elements of mathematical and population genetics, and statistical theory of the methods of human genetic analysis. Topics include Hardy-Weinberg equilibrium, models for polygenic and multifactorial inheritance, variance components estimation familial aggregation, linkage and association analysis, disequilibrium mapping and ascertainment problems.

04385 Advanced Bayesian Analysis. 3 credits. (All Tracks) (fall, every other year)
A combination of Bayesian principles, tools and methods; emphasis is on models, computations and analysis. Likelihood function, prior, posterior and predictive distributions, Bayes factors, HPD regions, conjugate and non-informative priors in the exponential family, Markov chain Monte Carlo methods for the generalized linear model, hierarchical models, restricted parameter spaces and censored data, examples of Bayesian analyses of complex biomedical models.

Bioethics (Master of Arts Courses)

10222 Ethics and Integrity in Science. 1 credit. (All Tracks) (online course, offered every spring semester and summer)
This course provides the basis for understanding the ethical issues related to basic scientific and medical research, including animal and human subject research, fraud and misconduct, and governmental, institutional, and researcher responsibilities. This course provides the necessary research ethics instruction required to satisfy the United States Public Health Service Policy on Instruction in the Responsible Conduct of Research for institutions receiving research funds from the Department of Health and Human Services.
Note: This is a required course for all MCW doctoral students.

10444 Research Ethics Discussion Series. 1 credit. (All Tracks) (offered every spring semester)
The course covers major topics in research ethics as they apply to biological scientists. The 10 sessions, each running an hour and a half, are moderated by a Co-Director of the course and a faculty member of the Center for Bioethics. Sessions begin with a brief overview of the topic provided by a faculty member with expertise in that area. Such presentations may include a case study to provide a basis for further discussion. The initial presentation is followed by comments from a panel of three or four faculty members who will discuss the topic from their particular perspective and experience. The remaining minutes of each session are used for an open discussion in which students have an opportunity to ask both focused and general questions related to the topic. Discussion of the questions involves students, panel members and moderators. Topics covered include: plagiarism, experimental design and data collection, data manipulation, publication and authorship, sharing information and reagents, animal use, patient/human subject interactions, IRBs, whistle blowing and conflicts of interest. Performance is assessed through an online, multiple-choice quiz that is completed within two days following each session. Prerequisite: 10222 Ethics and Integrity in Science.
Note: This is a required course for all MCW doctoral students.

10207 Introduction to Research Ethics. 3 credits. (All Tracks) (offered every other year)
This course provides students with a comprehensive introduction to the ethical issues involved in scientific, animal and human subjects research. After a brief look back at the history of research ethics, students will spend time considering issues that impact research in both the laboratory setting and in the clinical setting. This course provides the necessary research ethics instruction required to satisfy the United States Public Health Service Policy on Instruction in the Responsible Conduct of Research for institutions receiving research funds from the Department of Health and Human Services.
Note: This is a recommended course for all MCW doctoral students.