Materials Science and Engineering Doctoral Program
Graduate Student Handbook
Version 3.8.2: 04/08/2023

I. Introduction

This handbook describes the policies and procedures for the Materials Science and Engineering doctoral program (*https://nano.nd.edu/materials-science/*) at the University of Notre Dame. In this interdisciplinary program graduate students are also expected to adhere to the handbook for their home department or program:

- Department of Aerospace & Mechanical Engineering Graduate Studies Handbook
- Bioengineering Graduate Program
- Department of Chemistry and Biochemistry Guide to Graduate Studies
- Department of Chemical and Biomolecular Engineering Guide to Graduate Studies
- Department of Civil & Environmental Engineering and Earth Sciences Graduate Handbook
- Electrical Engineering Department Graduate Studies Handbook
- Department of Physics and Astronomy Guide for Graduate Students

The Graduate School policies regarding degree progress and requirements to maintain eligibility for financial support and health care subsidies are contained in the Du Lac, the University's student policy and procedure manual, and the Graduate and Professional Student Handbook. Nothing herein is to be interpreted as contrary to the regulations of the Graduate School.

This handbook provides the official policies of the degree program. Any deviation from these policies requires the written approval from the program Steering Committee which will then document the exception in the student's permanent file. Deviations will be considered on a case-by-case basis; an exception in a particular case will not imply a change in policy.

For questions regarding the graduate program please contact Derek Lake, NDnano Associate Director, 206 Cushing Hall, email: dlake@nd.edu, or the program director, Professor Alan Seabaugh 230A Fitzpatrick Hall, aseabaug@nd.edu.

II. Basic Responsibilities Of Students

Registration & Enrollment
A graduate student must meet the home department or program requirements to be full time as explained in the home department's graduate studies guide. This includes registration and enrollment, both responsibilities of the student.

Satisfactory Degree Progress

Students must be making satisfactory progress toward their degree and remain in good standing in accordance with their home department's policies. This includes but is not limited to completion of qualifying exams, successful candidacy exam review, dissertation completion and defense, etc. The exact degree milestones will be detailed in the home department graduate studies guide.

Grades

The most readily used means for assessment of the student's academic progress is through grades assigned in course work. The Graduate School grading system is on a four-point basis. Grades recorded for graduate courses are: A (4.0), A- (3.667), B+ (3.333), B (3.0), B- (2.667), C+ (2.333) and C (2.0). Students must meet the minimum GPA requirements for their home department. In the Materials Science and Engineering required courses, each student must receive a B or higher in each course for the course to count towards the Materials Science and Engineering degree requirements.

Teaching and Research Responsibilities

Most graduate students are supported by research grants and contracts. Each student is responsible for meeting the requirements of his/her research position, which should be considered a full-time position. Students should be on campus and meet with their research supervisor regularly.

Most departments in the Colleges of Engineering and Science require their graduate students to assist with teaching. The director of graduate studies in the student's home department or program may assign teaching assistant duties according to the policies of the department.

Holidays and Time-off

The policies for holidays and time-off for the home department or program should be followed.

Office and Laboratory Facilities

Each home department supports office space and individual research laboratories. Students are responsible for acquainting themselves with and following the proper safety procedures for the laboratories they use. Because the offices and laboratories are diverse in their purposes, procedures, and equipment, specific safety procedures are not listed here. However, all users of these offices and laboratories are to observe the following general safety and security procedures:

1. A student may be issued keys or electronic access to university buildings. Keys may not be traded among, loaned to, or passed on to other students and must be returned as soon as the need for regular access has passed.
2. Laboratory users share in maintaining its security and cleanliness. Laboratory doors are not to be propped open or left unlocked when the laboratory is unattended, and must be locked at the end of the working day.
3. Unauthorized users are not allowed into a laboratory.

4. Guests may be invited into a laboratory, but may not be left unsupervised. The home department is responsible for the guests' safety.

Safety

Office facilities and laboratory spaces have an integrated safety plan. Each student should be familiar with it, and each advisor or his/her designee should instruct students in laboratory safety. Each student should bring to the attention of the laboratory supervisor or advisor any unsafe laboratory situations they encounter. If a student does not feel that a concern has been adequately addressed, that student should contact the program director. The following general rules apply to all laboratories:

1. Students must complete assigned training through ComplyND before working in laboratory facilities.
2. Each student using a laboratory must be acquainted with all the particular safety procedures and safety equipment in the laboratory. These include the locations of emergency controls and the locations and use of all safety equipment and first aid supplies.
3. Students should contact their advisor or other laboratory management if they see an unsafe situation, or feel the need for additional or different personal protective equipment.
4. Graduate students who supervise undergraduate laboratories assume primary responsibility for safety procedures. If additional safety supplies (such as hard hats or safety glasses) are required, the course instructor should be notified.
5. Any graduate student developing a new experiment or acquiring new equipment will also be responsible for developing and recording the proper safety procedures associated with the new equipment.
6. Observed inadequacy of laboratory safety procedures or equipment must be reported immediately to a faculty member so that the situation may be corrected.
7. Violations of safety procedures or the creation of unsafe or unhealthy conditions must be reported to the responsible faculty. Failure to work safely or to maintain orderly, professional working environments will result in the forfeiture of all office or laboratory privileges.

In addition to the safety policies outlined here, students should review and understand the home department's safety policies.

Leaves or Study at Other Sites

Students should review their home department policies around leaves and study at other sites.

III. Program Structure

The Materials Science and Engineering doctoral program is administered by Notre Dame Nanoscience and Technology (NDnano) and is housed across participating departments and programs in the Colleges of Engineering and Science. The program is a Ph.D. program, and the Graduate School does not grant an M.S. degree in Materials Science and Engineering.

Administration

All policy-making and administrative authority in the Materials Science and Engineering doctoral program resides with the Steering Committee and the program director. Any policy question or administrative matter should be referred in writing to the Steering Committee via Heidi Deethardt, 206 Cushing Hall, MSE-list@nd.edu. Matters that cannot be resolved satisfactorily can be appealed to the Graduate School, via the Dean of the Graduate School. The program director is Professor Alan Seabaugh, 230A Fitzpatrick Hall, aseabaug@nd.edu.

Home Department or Program

Each student in the program will belong to a home department or program. The home department or program is the department or program to which the student was admitted. The home department or program in conjunction with the advisor will provide office and laboratory facilities for the student. The student is required to fulfill any teaching assistant, service, and professional development requirements as other Ph.D. students in the home department or program. When considering Materials Science and Engineering courses, the home department for Bioengineering students will be the same home department for the student as defined by the Bioengineering program. (See Bioengineering Studies Handbook Section III part B. *"Each student in the program is assigned to a home department. The home department is the department where the student's faculty advisor has their primary appointment."*)

Financial Support

Most full-time students receive a stipend. Funds for these stipends typically come from externally funded grants and contracts of the student's advisor. One-year Materials Science and Engineering Fellowships are available and awarded annually by the Executive Committee.

Materials Science and Engineering Fellowships

Materials Science and Engineering Fellowships will be awarded each year by the Executive Committee. The Fellowship is for one-year and is non-renewable. The application process is joint between the student and the student's advisor. The following items are required when applying for a fellowship: 1) A two-page research proposal written by the faculty advisor, 2) a one-page statement of interest from the student, 3) the student's curriculum vitae, and 4) a letter of support from the faculty advisor. Faculty interested in submitting a fellowship proposal on behalf of a student should contact Derek Lake, NDnano Associate Director, for full details on the fellowship proposal process. The Materials Science and Engineering Fellowships will typically be used in the student's second or third years of study. Students in this program are required to have a co-advisor that crosses disciplines and is encouraged to be from outside the department or program. Each student may only be awarded the Materials Science and Engineering Fellowship one time. A student does not have to be awarded a Materials Science and

Engineering fellowship to participate in the Materials Science and Engineering graduate program.

IV. Advising

One of the most important matters for graduate students is the choice of a faculty advisor. This choice can have a great effect on the student's time in graduate school and long-term career path. Students in this program should follow their home department or program policies to select a graduate research advisor. Students in this program are required to have a co-advisor that crosses disciplines and is encouraged to be from outside the department or program. ***Students should work with their primary research advisor to select a co-advisor within the policies laid out by their home department or program.*** Exceptions to the co-advisor requirement have to be approved by the Steering Committee.

Examination Committee

Each student should follow the home department or program guidelines for the selection of his/her examination committee. The student's co-advisor is expected to be part of the examination committee, which includes both the candidacy and defense examinations.

Professional Development and Career Planning

The Graduate Career Center resources are focused on graduate student success – helping each student to be the best prepared in order to obtain strong career outcomes after his/her time at Notre Dame. All Materials Science and Engineering students should meet any requirements with respect to the Graduate Career Center as stated in the home department's or program's policies. The Center is located in the Graduate School, 110 Bond Hall, and online at http://gradcareers.nd.edu/.

V. Program Requirements

Admission

Students can be admitted to the Materials Science and Engineering Program in one of two ways.

Incoming Students:

When applying to Notre Dame, incoming PhD students can select the Materials Science and Engineering degree that corresponds to the admitting department/program:

- Aerospace and Mechanical Engineering: Materials Science and Engineering - PhD
- Biochemistry: Materials Science and Engineering - PhD
- Bioengineering: Materials Science and Engineering - PhD
- Chemical Engineering: Materials Science and Engineering - PhD
- Chemistry: Materials Science and Engineering - PhD

- Civil and Environmental Engineering and Earth Sciences: Materials Science and Engineering - PhD
- Electrical Engineering: Materials Science and Engineering - PhD
- Physics: Materials Science & Engineering - PhD

Students will follow the admitting department's/program's existing process and timeline for recruiting and admissions. Each student will be asked to submit a one-page, advisor-approved overview of his or her research for review by the Materials Science and Engineering Steering Committee. The template for this research overview can be found in Appendix E.

Current PhD Student Transfers

With the support of their faculty advisor, current Notre Dame graduate students already pursuing a PhD degree in a participating department/program can transfer into the Materials Science and Engineering program (generally sometime in the first three years of their doctoral studies). Students considering a transfer should follow these steps:

- Review the program details, including the expectations for your thesis research and the courses needed to earn the Materials Science and Engineering degree.
- Discuss the opportunity to earn the Materials Science and Engineering PhD with your research advisor(s). (If you don't have a research advisor yet, discuss with your department's Director of Graduate Studies (DGS)). In this discussion, make sure that you and your advisor(s) are in agreement on how your thesis could or does meet the requirements of the Materials Science and Engineering degree. Also ensure that you'll be able to complete the courses required for the degree in your remaining time at Notre Dame.
- If you and your advisor(s) are in agreement about your joining the Materials Science and Engineering PhD program, email MSE-list@nd.edu to let the program staff know of your interest to pursue the degree.
- Submit a one-page, advisor-approved overview of your research for review/decision by the Materials Science and Engineering Steering Committee. The Steering Committee meets approximately quarterly for this purpose. The research overview template can be found in Appendix E.
- Once your research is approved by the Steering Committee, complete the form **available here**. (**Note:** Only current ND graduate students transferring into the program should fill out this form.) The program staff will work with your home department and the Graduate School to ensure your transfer into the program.

Course Requirements

Materials Science and Engineering students reside in a home department or program and are expected to meet the course requirements of the home department or program. Under the guidance of the faculty advisor in the host department, from a designated set of Materials Science and Engineering graduate courses (Appendix D). Two of the three courses must be outside the student's home department, and only one of those can be cross-listed within the student's home department. Cross-listed means that a course has a course number from two different departments. This cross-listing applies to the semester the course was taken, regardless of whether the course was cross-listed before or after the student completed it. The course catalog is the final reference as to the cross-listing of a course, regardless of what is printed on the MSE website or student handbook.

Each academic department or program determines whether these credits are electives or additional courses. (*MSAE is the attribute to identify Materials Science and Engineering Courses in the Notre Dame course catalog.*)

Materials Science and Engineering students typically complete the required Materials Science and Engineering course requirements from the approved course list. Deviations from the approved course list must be approved by the Academic Committee. These requests should be submitted to the MS&E administrative staff at MSE-list@nd.edu. Generally, transfer credit is not accepted in the Materials Science & Engineering doctoral program. This is because it is contrary to the program aims to provide interdisciplinary training, and to have this additional experience earned at Notre Dame.

The Academic Committee will make decisions on the addition or removal of courses on the list of approved Materials Science and Engineering graduate courses. Students and faculty members may petition the Academic Committee to have courses added. The request should be submitted to the MS&E administrative staff at MSE-list@nd.edu. The request will then be sent to the chair of the Academic Committee for consideration.

Degree Program

The Materials Science and Engineering graduate student must meet the requirements of that student's home department or program. In addition, this student must have a doctoral thesis that has a significant materials component as determined by the Materials Science and Engineering Steering Committee. If a thesis is not approved by the Steering Committee and the difference cannot be successfully resolved, then the decision can be appealed to the Executive Committee for review. The appeals can be made in writing to the committee via Heidi Deethardt, 206 Cushing Hall, MSE-list@nd.edu.

Research Overview

All students entering the program, either through direct admission or transfer, must have their research approved. The research approval occurs either through submission of the one-page research overview to the Steering Committee or through the Fellowship process.

Research Approval Via the Fellowship Process

The fellowship proposal process requires the advisor and co-advisor to submit proposed research for the student. If the advisors and student are awarded the fellowship, then the student's research is approved. No further research review by the Steering Committee is required.

Research Approval Via the Steering Committee Process
All students that have not been awarded a fellowship need to have their research approved by the Steering Committee. Once the student has selected an advisor, the student and advisor have agreed on a research project, and a co-advisor has been selected, then the student should submit a one-page research overview for consideration and approval by the Steering Committee. Typically, this research overview is submitted within the student's first three years of study. The research overview template can be found here. The completed research overview should be emailed to the Materials Science and Engineering administrative staff at MSE-list@nd.edu.

Qualifying Exam

Students will follow the qualifying exams policy guidelines as set out in the home department or program policies.

The Candidacy Examination

Students will follow the candidacy examination policy guidelines as set out in the home department or program policies. Each student will share a copy of the candidacy proposal with the Steering Committee when it is sent to the candidacy review committee. The candidacy materials should have the template cover page, that can be downloaded here. A copy of the candidacy proposal can be emailed to the MSE staff at MSE-list@nd.edu. The candidacy proposal will be reviewed to make sure that it still aligns with the student's research upon entering the program.

The Dissertation and Defense

Students will follow the dissertation and defense policy guidelines as set out in the home department or program policies. Each student will share a copy of the dissertation with the Steering Committee when it is sent to the committee in preparation for defense. The dissertation can be emailed to Heidi Deethardt at MSE-list@nd.edu. The dissertation will be reviewed to make sure that it still aligns with the student's research upon entering the program.

VI. FACILITIES AND SERVICES

A. Library

The University Library system consists of a number of libraries. Circulation policies and operating hours are available at each of the libraries. Students should make themselves aware of the resources the libraries provide and become more familiar with them by visiting the University library website, http://library.nd.edu/.

B. Computing Facilities

The Office of Information Technologies (OIT) oversees an extensive variety of computers, workstation clusters, and personal computer facilities throughout campus. The University has a wide range of software and printing services available for use by all students. For a complete current listing of University facilities, students should visit http://oit.nd.edu.

The Center for Research Computing (CRC) at University of Notre Dame is an innovative and multidisciplinary research environment that supports collaboration to facilitate multidisciplinary discoveries through advanced computation, software engineering, data analysis, and other digital research tools. The CRC is composed of four main groups with complementary expertise: computational scientists, software development, Center for Social Science Research, and high performance computing. For more information on the CRC visit https://crc.nd.edu/.

C. Laboratory Facilities

Students may work in a wide variety of laboratories across the University campus. These may be laboratories specific to the student's research group, or shared facilities that are supported by user fees.

D. Office Facilities

All full-time graduate students have access to personal office space. Offices are typically shared with other students. Each student will also have a mailbox located in or near the main administrative office in the building to which the student has been assigned. Students are expected to maintain professional office environments, to maintain a neat office, and to be respectful and courteous to their office mates and others in their office environment.

E. Copying Facilities

There are many copying facilities on campus, with services available at a charge. Many small machines are located in Hesburgh Library, branch libraries and home departments. Students should check with the administrative staff or their advisor to learn about local resources.

F. Student Government Service

Graduate students are responsible for the activities of the Graduate Student Government (GSG). Through a council of elected officers, appointed officers, and representatives from the departments of its constituent colleges, the GSG provides a variety of services and represents its membership on various University councils and committees. It publishes the bimonthly GSG newsletter, conducts a graduate orientation program, and sponsors workshops, travel grants, and various social and cultural activities. The GSG is the graduate students' official liaison with University administration, the Office of Student Activities, and the Library Administration. The GSG finances operations through a yearly fee assessed on all graduate students. The GSG maintains offices in W206A Duncan Student Center, 631-6963; their website is: https://gsg.nd.edu/.

G. Health and Counseling

There are additional services available to graduate students, described in the Bulletin of Information or on the web at: http://graduateschool.nd.edu/resources-for-current-students/.

University Health Services, located in the University Health Center, 631-7497, provides immediate, follow-up, and ongoing health care. The services provided include outpatient clinics, dispensing medication, administering allergy injections, laboratory and x-ray facilities, and a 25 bed inpatient unit. Health insurance is required of all international and full-time students. The University offers a plan for all students. A student's spouse and children have the option of purchasing health insurance through this plan. More information can be obtained by calling 631-6114. The University Counseling Center, located in the University Health Center, 631-7336, offers professional services to all graduate students and their families.

The University Counseling Center is available to assist students in meeting the challenges that are an integral part of their Notre Dame experience. Their professional staff of licensed psychologists, social workers, psychiatric providers, and masters-level psychologists-in-training are highly skilled in helping students address the difficulties they may encounter, and empowering them to make the most of the opportunities available to them at Notre Dame. The University Counseling Center specializes in treating the mental health concerns that are prevalent in a diverse university student body. The University Counseling Center is located in the University Health Center and can be reached at 631-7336. More information can be found by visiting https://ucc.nd.edu/. All services are free of charge and confidential.

The University has excellent athletic and exercise facilities; most are available free of charge. More information can be found at https://recsports.nd.edu/.

H. Career and Placement

The University's Graduate Career Services provides assistance with post-graduate placement and professional development through online services and the guidance of its graduate career consultants.

I. International and Religious Services

The International Student and Scholar Affairs office, in 105 Main Building, supports our F-1 and J-1 students on immigration and visa status matters, and serves as a liaison with sponsoring agencies and the U.S. government. Submit your inquiries to issa@nd.edu or call them at 631-1138.

Campus Ministry, 116 Coleman-Morse Center, 631-7800, offers programs and organizations to serve students' spiritual needs across a full range of faith traditions.

J. Graduate Student Life

A unit within the Division of Student Affairs and in cooperation with the Graduate School, Graduate Student life (http://gradlife.nd.edu/) is committed to enhancing the educational experience and quality of life for Notre Dame students pursuing advanced degrees. The Graduate Student Life website contains reference links for special events and programs, family resources and information regarding campus life in general. A helpful Q&A weblog to answer questions is also featured.

APPENDICES

A. ACADEMIC INTEGRITY

In questions involving academic integrity, the student is referred to the general policy found in the Graduate School Bulletin of Information. The department expects all students to maintain and promote the highest standards of personal honesty and professional integrity. These standards apply to examinations, assigned papers, projects and preparation of the thesis or dissertation. Violation of these standards, which includes, but is not limited to cheating in examinations, plagiarism and fraudulent practices in conducting research or reporting the results of such research, may result in suspension or dismissal.

Primary authority for judgment and decision on matters of academic integrity lies with the course instructor for issues that arise in the classroom, or the faculty research advisor for issues that arise in research. Unsettled disputes should be referred first to the director of graduate studies in the student's home department and next to the student's home department chair, each of whom can serve as arbiters at the department level. Any further appeal should be directed to the Graduate School.

B. FACULTY

For faculty affiliated with the Materials Science and Engineering program, click on the following: https://nano.nd.edu/faculty/?dept=&program=materials-science&id=

D. MATERIALS SCIENCE AND ENGINEERING GRADUATE COURSES

Material Structure – Soft, hard, and heavy matter

CBE 60561 – Structure of Solids. This class seeks to provide students with an understanding of the structure of solids, primarily as found in metals, alloys, and ceramics applied in technological applications. The structure of crystalline solids on the atomic level as well as the microstructural level will be discussed. Imperfections in the arrangements of atoms will be described, especially as regards their impact on properties. The study of structure through X-ray diffraction will be a recurring theme. A sequence of powder diffraction laboratory experiments (four to five class periods) also will be included.

CHEM 60618 – Chemical Crystallography. This course covers the theoretical and practical aspects of Small Molecule X-ray Crystallography. There will be both lecture and laboratory sessions with this course. Topics covered include: crystal growth, the diffraction experiment, space group analysis, symmetry, structure solution and refinement, powder diffraction, use of typical software for diffraction studies. The laboratory session will cover the practical aspects of crystal selection and the use of X-ray diffractometers.

CHEM 60438 – Polymer: Principle to Practice. This course offers the basic physical and organic chemistry knowledge in polymerization reactions. Topics to be covered include mechanisms of polymerization reactions; polymerization kinetics and thermodynamics; relationship of physical properties to structure and composition; correlations of applications with chemical constitution; functional polymers for medicines and electronics. The course is recommended for students with special interest in polymer materials and future plan on polymer research and professional studies.

CE 60382 – Actinide Chemistry. This course is intended to provide students with a basic understanding of the fundamental chemical and physical properties of actinide elements. Lectures will focus on solution chemistry, bonding, kinetics, and thermodynamics in the context of the behavior of actinides in the environment and within the nuclear fuel cycle. Particular emphasis will be placed on solution chemistry of the actinides and interactions at the solid-water interface.

CBE 60457 – Polymer Science & Engineering. This course is an intermediate level introduction to the fundamental chemistry and physics of polymer materials. The course is designed to meet the needs of students in all science and engineering disciplines who are interested, or already engaging in polymer related research. The lectures will focus on the underlying concepts and principles in polymer materials, emphasizing the interrelationships between synthesis, structure, processing, properties and performance, and demonstrate them in the context of their everyday use as well as real-world advanced engineering applications. Major topics in polymer chemistry, physics, and engineering will be covered including: general introduction of polymers, major classes of polymerization reactions and kinetics, microstructure and morphology, polymer properties (thermal, mechanical, etc.), polymer thermodynamics, polymer characterization techniques, and plastics engineering and processing methods. The successful students will emerge from the course with a current, sound knowledge of polymer concepts and an ability to apply them in career situations.

CBE 60550 – Electrokinetics of Membranes. Nonequilibrium ion transport features in an ion elective membranes such as rectification, hysteresis and oscillation, are scrutinized at a fundamental level to understand related physiological phenomena and to develop new biosensing and separation technologies.

CBE 60556 - Polymer Engineering. A course for seniors and graduate students in science and engineering who are interested in applications of engineering to polymer science and technology. Topics include polymerization reactions, reaction engineering of polymer systems, structure, properties, and processing. Emphasis is placed on the use and extension of fundamental chemical engineering principles and methods of analysis (such as those emerging in reaction engineering, solution thermodynamics, and transport phenomena) to polymer related topics.

CBE 60667 - Mass Transfer Membrane Systems. Membranes are discrete interfaces that mediate the transfer of chemical species between two adjacent phases. For example, naturally-occurring membranes are central to many of the functions of biology, while engineered membranes can be designed to produce potable water from seawater, to control the release of therapeutic drugs, or to enable energy storage technologies. Regardless of where a membrane is found, elucidating and quantifying the processes that control mass transfer through it is essential to understanding, and potentially enhancing, its function. In this course, the transport phenomena and thermodynamic principles that are used to describe the rates of mass transfer are defined. Subsequently, these principles are used to contemplate the molecular and structural design of materials that can be manufactured to produce next-generation membranes that help to address grand societal challenges.

CBE 60725 - Principles of Molecular Engineering. The objective of this course, intended for both upper level undergraduate and graduate students, is to illustrate the emerging field of molecular engineering. By fusing concepts from chemistry and materials science, molecular engineering seeks rational design of chemical building blocks for organized systems and materials. Students will gain a fundamental perspective for how non-covalent interactions and designed molecular motifs can dictate the structure, function, and properties of resulting engineered systems. This will include an appreciation for the role of intermolecular forces in governing the behavior of these molecules as they interact with each other and with their environment (typically a solvent). Additionally, illustrative examples will point to the power of strategies rooted in principles of molecular engineering to create highly controlled and functional materials. topics will include: non-covalent interactions, molecular design, thermodynamic driving forces, solvent effects, molecular self-assembly, supramolecular chemistry, molecular & materials characterization techniques, and applications of molecular engineering for diverse uses in energy, medicine, computing, formulation science, industrial applications, and food sciences.

Nanostructure Materials

CBE 60577 – CHEM 60577 - Nanoscience and Technology. This course focuses on the unique scientific phenomena that accrue to matter with characteristic nanometer-scale dimensions and on the technologies which can be constructed from them. Special optical, electronic, magnetic, fluidic, structural and dynamic properties characteristic of nanostructures will be addressed. Demonstration of the characterization techniques, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive analysis (EDS) and others is an important part of the course.

AME 60679 – Nanoparticles in Biomedicine. Nanoparticle science and engineering will be introduced including the processing (synthesis and surface modification), structure (physical and molecular), and functional properties (biological, electrical, magnetic, mechanical, optical, X-ray, etc.) that enable biomedical applications in drug delivery, imaging, sensing, and tissue regeneration.

Solid State Materials

AME 60733-01 - Solar Energy: Photovoltaic Systems. This is an interdisciplinary course which covers basic science and engineering applications of solar cell technologies. The course is divided into two modules: the properties of sunlight, which is the source of energy, and solar cells themselves. In the first module the students learn about the sun's resources, characteristics of sunlight, tracking the sun, optimizing the tilt of solar panels for different seasons and performing solar site obstacle survey. The second module introduces the students to a solar cell design principles including review on semiconductor properties and p-n junction device operation, optical and electrical design of a solar cell, solar cell interconnection and fabrication of a solar panel. The course will also examine next-generation solar cell concepts.

EE 60556 – Fundamentals of Semiconductor/Physics. Treatment of the basic principles of solids. Topics include periodic structures, lattice waves, electron states, static and dynamic properties of solids, electron-electron interaction transport, and optical properties.

EE 60576 – Electronic and Photonic Materials Principles of materials science applied to materials issues in fabrication, operation, and reliability of microelectronic devices.

PHYS 50501 - PHYS 60501 – Intro to Solid State Physics. The course is intended to introduce the principles of the behavior of electrons and phonons in solids, advanced concepts and applications, such as low-dimensional systems and superconductivity, and set the conceptual framework needed for future study and graduate research in condensed matter physics or technology-related industry. Topics will include: crystal structure and diffraction, phonons and heat capacity, free electron gas and elementary band theory, semiconductors, magnetism, and superconductivity.

CBE 60435 – CHEM 60435 - Electrochemistry and Electrochemical Engineering. This course addresses the fundamentals and applications of technologies that rely on heterogeneous electron transfer reactions. The first part of the course addresses fundamental aspects of electron transfer reactions at electrified interfaces, including band structure of metals and semiconductors, electrochemical potentials, electron transfer kinetics and Marcus theory, potential step and potential sweep experiments, hydrodynamic electrochemistry, potentiometry and ion-selective electrodes, impedance measurements, and electrochemical instrumentation. The second part of the course addresses applications to energy storage (batteries, fuel cells, supercapacitors), energy conversion (photovoltaics), bioelectrochemistry, including neurochemistry, corrosion, and electrolysis and electroplating.

CBE 60535 – Electrochemical Energy. In this class, students learn the fundamental theoretical concepts underlying electrochemical systems, but do not learn how these concepts govern the function of engineered electrochemical systems. This course combines the study of charge transfer at electrode/electrolyte interfaces with the development of practical materials and processes. The development of the technology involves the study of the electrochemical reactors, their voltage and current distribution, mass transport conditions, hydrodynamics, geometry as well as the quantification of overall performance in terms of reaction yield, conversion efficiency, and energy efficiency. This course examines the operational principles of electrochemical energy storage devices (batteries and capacitors), energy conversion devices (fuel cells, electrolyzers), electrodeposition, corrosion, and bioelectrochemical interfaces. The emphasis is on materials and device design based on fundamental chemistry and physics concepts that govern the properties and performance of the materials/devices involved. Specific systems of study will include electrode and electrolyte materials for primary (non-rechargeable) and secondary (rechargeable) batteries including lithium-ion batteries, electrochemical capacitors, proton exchange membrane fuel cells, solid oxide fuel cells, alloy electrocatalysts, mixed ionic-electric conductors, and biosensor development.

CBE 60623 – Surface Science. This course covers the structure and properties of solid surfaces and interfaces and the dynamics of chemical reactions at surfaces. Topics include geometrical structure, surface morphology, electronic structure, surface composition, kinetics and dynamics (adsorption, scattering, vibrations, diffusion, desorption), structure and reactivity of surface molecules, non-thermal excitations of surfaces, and modern ultrahigh vacuum experimental techniques.

EE 87039 – Quantum Optics and Nanophotonics This course will introduce quantum optics and nanophotonics, emphasizing the foundation of these two fields. The material will include quantization of the electromagnetic field, quantum states of light, light-matter interactions, plasmonics, metamaterials, and recent advances that merge the fields of quantum optics and nanophotonics.

PHYS 80501 - Solid State Physics Free electron theories of solids; Drude and Sommerfeld theory; crystal and reciprocal lattices; diffraction; Bloch electrons; band structure and the Fermi surface; cohesive energy; classical and quantum theory of the harmonic crystal, phonons; dielectric properties of insulators; semiconductors; paramagnetism and diamagnetism, magnetic ordering; superconductivity.

EE 80688 – Advanced Solid State Physics This course will provide advanced discussion of interactions that are fundamental to solid state and semiconductor systems for graduate students. Topics that will be covered: free-electron theories, electrons in weak periodic potentials, tight-binding, phonons, semi-classical models for electron dynamics, beyond the relaxation-time approximation, dielectric properties of insulators, and magnetism. While there are no prerequisites for the course, students are expected to have a working knowledge of quantum mechanics and introductory semiconductor or condensed matter physics.

EE 80656 – Advanced Semiconductor Physics The class will provide graduate students with a solid understanding of the basic underlying physics of semiconductors that lead to practical applications. Starting from a review of quantum mechanics and specifically perturbation theory, we will cover electronic band structure, electron-photon and electron-phonon interactions, charge scattering by defects and transport, and optical properties of semiconductors. Quantum confinement effects in optical devices, ballistic transistors, and tunneling FETs will be covered. The modern bottom-up approach to electronic properties from the non-equilibrium Green's functions will be covered. Topics 1) Recap of quantum mechanics 2) Formulation of the transport problem: Electric current 3) Ballistic transport and nanoscale FETs 4) Time-independent perturbation theory 5) Electron band structure and quantized states 6) Time-dependent perturbation theory 7) Electron-photon interactions, optical properties, LEDs and Lasers 8) Electron-phonon interaction and scattering 9) Electron-defect interaction and scattering 10) Mobility, drift-diffusion, quasi-ballistic FETs 11) High-field phenomena: Tunneling transport and tunnel-FETs 12) Bottom-up approach to transport: Non-Equilibrium Green's Function (NEGF) approach.

PHYS 90507 – Topology and Dirac Fermions in Condensed Matter This course is an introduction to the burgeoning field of topological and Dirac matter. It covers the following topics: Dirac, Weyl and Majorana fermions, the Jackiw-Bell solution to the Dirac equation, the Berry phase, topological invariants, the band structure of graphene and experimental proofs of its Dirac nature, toy models of topological systems (Kane-Mele, Su-Schrieffer-Heeger, ..., realistic topological materials and their band structure, experimental observables of non-trivial topology (quantum spin Hall effect, band-inversion, ...).

CHEM 90616 - Solid State Materials and Chemistry Solid-state materials are the reason we can feed the world, store information in computers, harness solar power, and so much more. This class is designed as an introductory discussion of the physical and electronic structure of solid-state materials with an emphasis on structure-property relationships. The course is aimed at engaging a broad range of scientists and engineers interested in the chemistry and applications of solid-state materials. Perhaps most importantly, the class takes a practical approach with the goal of making participants familiar with a wide variety of materials, methods for materials characterization relevant to students' research projects, and applications including energy utilization, catalysis, and optoelectronics. We will follow many tangents into the fun and wide world of materials chemistry and how it relates to our modern (and ancient) society.

Emergent Phenomena at Surfaces and Interfaces

CBE 60625 – Principles of Heterogeneous Catalysis. This course will provide a comprehensive overview of heterogeneous catalysis with particular focus on catalyst synthesis, modern characterization techniques, kinetics, and reaction mechanisms for energy-related applications. Emphasis will be placed on 1) understanding the synthesis and properties of a variety of solid catalysts including carbides, phosphides, zeolites, bimetallic catalysts, tethered catalysts, and metal-organic frameworks, and 2) in-situ/operando techniques to aid in the design of new materials.

CE 60300 – Geochemistry. An introduction to the use of chemical thermodynamics and chemical kinetics in modeling geochemical processes. Special emphasis is placed on water-rock interactions of environmental interest.

CE 606355 - High-Temperature Geochemistry. This course examines the generation and evolution of magma from a physicochemical standpoint. Using actual geochemical datasets and samples in conjunction with research papers will allow the student to develop the skills for formulating petrogenetic models that are thermodynamically viable. These skills will be used in their individual research projects. The student is evaluated by two exams, weekly homework assignments, and a research paper.

EE 60568 – Fundamentals of Photonics. The fundamental physics and engineering of photonic devices will be explored in this class. We will start with Maxwell's equations and study light propagation and interaction with materials, diffraction theory, photon statistics, waveguides, lasers, and optoelectronics. Experience with vector calculus, frequency domain (Fourier) analysis, and previous coursework in electromagnetism are strongly recommended. Appropriate for both graduate students and advanced undergraduate students.

Biomaterials

AME 60571 – Structural Aspects of Biomaterials. Structure and mechanical functions of load bearing tissues and their replacements. Natural and synthetic load-bearing biomaterials for clinical applications are reviewed. Biocompatibility and host response to structural implants are examined. Quantitative treatment of biomechanical issues related to design of biomaterial replacements for structural function. Material selection for reconstructive surgery is addressed. Directions in tissue engineering are presented.

AMD60572 – Introduction to Biomechanics. This course is an introduction to the application of mechanical engineering analysis to understand topics in biology. Topics will include development, disease, diagnosis, treatment, imaging, and mechanical testing in a variety of biological systems across scales.

AME 60672 – Cell Mechanics. The effects of mechanical loading on cells are examined. Mechanical properties and material structure of cell materials are reviewed. Filaments, filament networks and membranes are examined. Mechanics of flow induced effects, adhesion cell-substrate interactions, and signal transduction are examined. Experimental techniques are reviewed.

AME 60676 – Cancer Engineering. Applying engineering concepts to cancer biology allows for the design of new models, methods, and technologies for improved diagnostics, monitoring, and treatment. We will explore the barriers in the tumor microenvironment that thwart drug delivery and efficacy and tumor-fighting immune cells. Through didactic lectures, expert seminars, and in-class projects based on the primary literature, we will examine how cutting-edge engineering approaches can be used to overcome these barriers and improve treatment outcomes.

CBE 60888 – Cellular and Physical Principles of Bioengineering. This course covers the breakdown of biological systems at molecular, cellular and tissue levels. It evolves to the design and synthesis of biomaterials at a molecular scale used in manipulating and targeting biological systems, including biotechnology and biomedical engineering. For these purposes, we will learn what is inside a cell, molecular machines, nerve impulses, binding thermodynamics and kinetics in biological systems, chemical forces and molecular self-assembly.

Materials Characterization

CHEM 60532 – Optical Spectroscopy. Principles and applications of spectroscopic measurements and instrumentation. Atomic and molecular absorption, emission, fluorescence, and scattering, emphasizing physical interpretation of experimental data.

CBE 60727 – CHEM 60727 – Ambient methods for Surface Characterization. This course develops fundamental principles for characterizing surfaces and interfaces, particularly thin films, using infrared spectroscopy, ellipsometry, electrochemistry, and contact angle measurements. The material will cover reflection of light from surfaces, which is relevant to surface infrared spectroscopy, surface plasmon resonance and ellipsometry, surface energies, adsorption isotherms, and some fundamental aspects of electrical double layers, zeta potentials, and mass transport in electrochemistry.

EE 80603 – Advanced Electron Microscopy. Course is an introduction to the fundamental basis and operations of transmission electron microscope and is required for all students who plan using the TEM in their research. Goals: The course goal is for the students to become competent, research-level experts in transmission electron microscopy. They will understand the functions of the TEM and how it works. They will be competent in basic operating techniques, and ready to learn more advanced ones as needed There will be a lectures (2 per week) and laboratory demonstration (3 hours/week). Topics will include: Electro-optics of the TEM - Image formation and imaging modes -Diffraction theory and Diffraction patterns - Dark and bright field imaging -Image interpretation -High resolution microscopy and Lattice imaging - Sample preparation

Materials Processing

EE 60546 – I C Fabrication. This course introduces the students to the principles of integrated circuit fabrication. Photolithography, impurity deposition and redistribution, metal deposition and definition, and other topics. Students will fabricate a 5000 transistor CMOS LSI circuit.

CBE 60910 – Materials Processing. This course covers a limited number of materials processing techniques used by materials researchers as well as industrial manufacturers. The primary areas to be covered include thin film processing, fine ("nanoscale") particle processing, crystal growth, and a few selected ceramics processing techniques. Within each of these areas various techniques will be discussed, with both the theoretical and practical aspects being described.

CE60323 – Advanced Physical – Chemical Water Treatment Processes. The objective of this course is to learn the fundamentals and design principles of advanced water treatment processes, including reactor analysis, redox reactions, adsorption, membrane filtration, ion exchange, air stripping, photolysis, advanced oxidation, and catalysis.

Computational Modeling

PHYS 60050 – Computational Physics. This course will provide a basic foundation in the skills and knowledge needed for computational physics. The course has three major parts: (1) Programming basics, with Python; (2) algorithms and methods, frequently used in computational physics and (3) physics projects for turning numerical calculations into solutions to real problems. Topics will include foundations of programming, principles of numerical analysis, interpolation and extrapolation, methods for solving ordinary and partial differential equations, random processes, Markov Chains, basic statistics, graphical representations. Applications include problems from classical physics (mechanics, electrodynamics), statistical mechanics, nuclear physics, basic network science and machine learning. The main goal of this course is to introduce the students to computational thinking in solving physics problems. In that sense this is not a numerical analysis math course but a course about how to tackle a physics problem with a computer, how to perform computational "experiments" to answer questions about a physical system.

CBE 60501 – Machine Learning for Chemical Engineers. Machine Learning (ML) is an important technological tool affecting society in myriad ways. Chemical engineering is not the exception. Students will be exposed to multiple examples within the chemical engineering discipline to appreciate the potential of ML as well as its limitations. The course is structured to provide a practical introduction to machine learning for chemical engineers. Topics to be covered include regression, supervised learning, unsupervised learning, feature extraction and other tools relevant to chemical and molecular engineering (SMILES, RDKit, etc.). The course will emphasize practical programming skills using Python implementations and will use case studies in chemical engineering. Students should have strong math and Python skills. Students who have already taken classes such as Numerical Methods and Statistical Analysis, Linear Algebra, Calculus, and Thermodynamics should have the necessary background to be successful in this course. Materials Science and Engineering students are expected to have a materials topic for the final course project.

CBE 60547 – Modern Methods in Computational Molecular Thermodynamics and Kinetics. This course will introduce the basis of modern approaches to computing the thermodynamics and kinetics of gas-phase, condensed-phase, and surface chemical reactions from first principles. Quantum chemical wavefunction and density functional approaches for treating the electronic structure of molecules, solids, and surfaces will be described. Optimization methods and statistical mechanical techniques for determining structures, spectroscopies, and thermodynamic and kinetic properties will be covered. Software for calculating these properties will be introduced and applied in hands-on exercises and a class project.

CBE 60553 – Advanced Chemical Engineering Thermodynamics. This course is focused on an advanced treatment of thermodynamic concepts. An introduction to molecular thermodynamics is given, followed by detailed treatments of phase equilibrium, equation-of-state development and activity coefficient models.

CBE 60642 – Molecular Thermodynamics. This course examines advanced topics in thermodynamics and statistical mechanics, including phase transitions, lattice models, renormalization group theory, critical phenomena, physical meaning and interpretation of correlation functions, classical partition functions and collective variables, liquid theory, molecular simulations of fluids and ordered phases, structure and dynamics of complex media, and supercooled and glassy materials.

AME 70791 – Molecular Level Modeling for Engineering Applications. This graduate level course is intended for engineering graduate students with interests in the simulation of materials and studying their properties at the molecular level using different atomistic simulations techniques. This course will introduce the basics of statistical thermodynamics and classical Monte Carlo and molecular dynamics simulations. With the fundamentals, students will learn how to use the knowledge and techniques to study engineering problems such as mass diffusion and heat transfer. It will also emphasize hands-on exercises in which students will use these techniques to model different materials including gas, liquid, solid, the phase transition among these different phases. Structural, flow and thermal properties of materials will also be studied. Students will be required to program their own code for small projects and will be using open source software, such as LAMMPS, for larger projects.

Quantum Mechanics

EE 60587 – Introduction to Quantum Mechanics. The course focuses on those aspects of quantum theory that are of particular relevance to electrical engineering. It is intended to give seniors and first-year graduate students a working knowledge of quantum mechanics at a level sufficient to illuminate the operation of standard and advanced quantum devices. Topics include classical mechanics versus quantum mechanics, early quantum theory, Schrödinger formulation, time-dependent and time-independent Schrödinger equation, Dirac formulation, Bloch theorem, magnetic effects, open quantum systems, and density matrices.

E. Student Research Overview Template

The Microsoft Word Template (.docx) file for the research overview can be downloaded here.

Interdisciplinary Materials Science and Engineering program research overview

Student: **Date:**

Advisor: **Department:**

Co-Advisor: **Co-Advisor Department:**

Year of study:

Research Title:

Research Overview: *One page maximum, Arial font size 10.*

Include the following sections:

<u>Background</u>

<u>Research Goals</u>

<u>Impact</u>

<u>References</u> *(not part of page limit)*