The Chemical Engineering Ph.D. Program

Department of Chemical and Biomolecular Engineering
University of Delaware Newark, DE 19716
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Introduction

For an engineer, the Ph.D. represents the final phase of formal academic training, in preparation for a variety of careers in industry, government, and academia. The Ph.D. program aims to equip students to conduct research; enable them to develop the maturity of judgment necessary for critical, creative, and independent thinking; and prepare them to contribute to scientific and engineering knowledge in a particular area of scholarship. The degree of versatility necessary to succeed in research and, in general, to be a productive member of the profession, requires a breadth of knowledge of chemical engineering fundamentals and their proper application.

The requirements specified below represent the minimum that the department expects every student to meet. They are designed to be sufficiently flexible to accommodate differences in interests, aptitudes, and expected career paths among students. Students are encouraged to take the initiative in seeking opportunities for formal and informal intellectual exploration beyond the guidelines imposed by the degree requirements. Keep in mind that these guidelines will change with time, and that the faculty will continue to refine and improve the Ph.D. program in consultation with the graduate students and Graduate College.

Admissions

Admission to the graduate programs at the University of Delaware is selective and based on the number of well-qualified applicants and the limits of available faculty and facilities. Those who meet stated minimum academic requirements are not guaranteed admission, nor are those who fail to meet some of those requirements necessarily precluded from admission if they offer other appropriate strengths. The Department encourages applications from candidates with research experience (undergraduate or industrial), as well as those with practical industrial experience after the baccalaureate.

Minimum admission requirements (in brief):

- A baccalaureate degree in the field or in a closely allied field of engineering, science, or mathematics.
- A minimum undergraduate grade-point average in engineering, science, and mathematics courses of 3.0 on a 4.0 scale.
- A minimum of three letters of strong support from former teachers or supervisors.
- Non-native speakers of English (international students) are required to achieve a minimum score of 600 on the paper-based TOEFL (PBT) and 100 for iBT.
- A personal statement that includes aspects of motivation to enroll in graduate studies, particularly with the graduate program in CBE at Delaware, prior education, research, or work experiences and how these experiences prepare the applicant for and inform their interest in graduate studies.
- GRE scores are no longer used in admissions to the graduate program. Applicants are asked to enter a future GRE exam date into the program application when prompted as a placeholder; entering any future date will allow your application to be sent on to our review committee where it will receive full consideration. If you wish to submit a GRE score with your application, reporting your scores is entirely optional; however, the submitted GRE score will not be reviewed and will have no bearing on evaluation of your application.

Application Deadlines:

- January 3: To receive priority consideration for admission and full consideration for department funding
- June 6: Final deadline to apply

Course Requirements

The aim of the course requirements is to establish a foundation of technical knowledge in chemical engineering. This foundation should foster a fundamental understanding of basic principles in general, while also providing depth in certain specific areas. An overall GPA of 3.00 or above must be maintained in courses taken toward meeting these requirements.

There are four components to the course requirements:

- Chemical and biomolecular engineering science core
- Chemical and biomolecular engineering seminar
- Chemical and biomolecular engineering concentrations
- Chemical and biomolecular engineering technical electives

The chemical engineering science core and chemical engineering concentration courses should all be taken during the first year prior to the qualifying exams. Five credits of chemical engineering electives are required. At least three of these credits must be at the 800-level; the remainder may be at the 600- or 800-level, with the possibility of substituting suitable courses from outside chemical engineering. The chemical engineering technical electives may be started during the fall semester of the first year and are usually completed during the second year. Nine credits of CHEG 969-xxx Doctoral Dissertation are also required. These credits should be taken *after* all other course work is completed and after being admitted to candidacy.

The curriculum is reviewed each year and updated often. A typical schedule of courses for the first year is shown below:

FALL I
CHEG 807 Modeling, Analysis, and Acquisition of Data (2 credits)
CHEG 810 Molecular Thermodynamics (2 credits)
CHEG 820 Kinetic Processes (2 credits)

FALL II
CHEG 802 Introduction to Data and Systems Analysis (2 credits) OR
CHEG 811 Chemical Interfaces and Surfaces (2 credits)[1]
CHEG 821 Diffusive Transport Processes (2 credits)

FALL (REGULAR)
CHEG 800 Chemical and Biomolecular Engineering Seminar (1 credit)
CHEG 6xx/8xx Technical Elective

SPRING I
CHEG 803 Advanced Scientific Communication (2 credits)
CHEG 8XX Concentration Module (2 credits)

SPRING II
CHEG 8XX Concentration Module (2 credits)

SPRING (REGULAR)
CHEG 6xx/8xx Technical Elective

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[1] Students may opt to take both *Introduction to Data and Systems Analysis* AND *Chemical Interfaces and Surfaces* in the Fall. In this case, only one 2-credit Concentration Module would be required in the Spring.

All students in the Ph.D. program are required to take an additional credit of CHEG 800 Chemical and Biomolecular Engineering Seminar during their fifth semester in the program. An overview of course and non-course requirements and timeline to progress toward a Ph.D. degree is provided in **Appendix A**.

A graduate student who receives a C+ or lower letter grade in any core graduate course must retake the course. Students who receive one or more B- grades in any core graduate course may choose not to retake the course as long as the student meets the overall 3.00 GPA requirement in the graduate classes.

Chemical engineering concentration option

All students are required to complete an additional four credits of advanced chemical engineering coursework that may take the form of a concentration. Concentrations consist of two 2-credit modules as defined below. Students opting to undertake a concentration must declare their concentration by the end of the Fall semester of their first year. Students who opt not to complete a concentration may meet the 4-credit additional coursework requirement by taking any combination of two additional 2-credit advanced chemical engineering modules.

Biomolecular Concentration
CHEG 840 Rate Processes & Dynamics for Microbial Systems (2 credits)
CHEG 843 Rate Processes & Dynamics for Mammalian Cellular Systems (2 credits)

Catalysis and Energy Concentration
CHEG 850 Electrochemical Processes (2 credits)
CHEG 851 Applied Thermodynamics (2 credits)

Data and Systems Concentration
CHEG 860 Process Systems Engineering: Mathematical Modeling and Optimization Principles (2 credits)
CHEG 861 Data Science for Chemical and Biomolecular Engineering (2 credits)

Soft Matter Concentration
CHEG 830 Continuum Transport in Materials (2 credits)
CHEG 832 Soft Materials, Colloids, and Polymers (2 credits)

No Concentration
Any combination of two 2-credit modules of advanced chemical engineering coursework not otherwise counted towards the student's core course requirements.

Sample schedules for the graduate coursework as well as short course descriptions for core courses and concentration modules are provided in **Appendix B**.

Ph.D. Qualifying Procedures

The Ph.D. qualifying procedures serve several purposes. They provide the faculty an opportunity to evaluate each student's analytical skills and ability to think critically and generate original ideas. In addition, qualifying procedures provide students a chance to practice their communication skills and faculty an opportunity to evaluate those skills. The qualifying procedures consist of an oral exam, a written report, and performance in the program coursework.

The qualifying exam is an oral examination given toward the end of the student's first year, after completion of the core courses. This schedule ensures that all students have the necessary chemical engineering background to take the exams and allows students to become involved in their research in an efficient and effective manner. To avoid unnecessary delays in formal admission to the Ph.D. program, students are given a single opportunity to take and pass the qualifying exams. The faculty feel strongly that we have more than enough information to make an appropriate decision about Ph.D. candidacy after students have spent a full year in the department.

The central formal component of the qualifying procedures is an oral examination that typically takes place near the end of August of the students' first year, unless other legitimate activities, such as a student's participation in a formal graduate training program, compel a postponement. The oral exam is intended to evaluate each student's abilities in several areas: creative thinking, progress in understanding and formulating a research project, mastery of the relevant underlying chemical engineering fundamentals, and effective communication of ideas in both oral and written forms. The specific guidelines for the oral exam are subject to change as the technology of the oral presentation advances, and as needed to improve the examination process. The procedures are as follows:

Each **oral exam** lasts 60 minutes. The first 12-15 minutes are reserved for oral presentation with the remaining time reserved for faculty questions. Presentation files (Powerpoint of PDF) are used. Each student's exam is administered by a group of at least five faculty, including at least two members of the student's dissertation committee, and the dissertation advisor. It is the student's responsibility to establish the dissertation committee prior to scheduling the exam, in consultation with the research advisor.

In preparation for the exam, students are also required to prepare a **written document**, to be made available to the faculty in electronic form (as a PDF file) at least 2 weeks before the exam, with a common deadline for all students set by the department each year. The written document should contain the following four elements:

1. A title page stating the title of your dissertation, your full name, and your dissertation advisor's name. This title page should not have any other text besides these three items.
2. The main document, including all tables and figures, should not exceed 10 pages on standard U.S. Letter paper.
3. Any (appropriate) number of pages (beyond the 10-page limit of the main document) listing relevant references in a bibliography using the format listed in the NSF grants preparation guide website. "*Each reference must include the names of all authors (in the same sequence in which they appear in the publication), the article and journal title, book title, volume number, page numbers, and year of publication*."
4. One page of an appendix (not counted as part of the main document's 10-page limit), which outlines goals, plans, and a timeline for the proposed dissertation research, with particular emphasis on the goals for the coming year.

You are expected to <u>adhere strictly</u> to the following format in all four elements listed above:

- Times New Roman with font size 11, OR Arial with font size of 10, OR Computer Modern with font size 11 (if you use LaTeX) for all text in the 10-page report and appendix, including figure captions, tables and references/bibliography.
- No more than six lines of text within a vertical space of one inch in the 10-page report and appendix, including figure captions, tables and references/bibliography.
- Margins, in all directions of the page, must be at least one inch. Do not include any text (e.g., references, footnotes, etc.) or figures within these 1-inch margins. Only page numbers can appear within the margin region.

Failure to comply with these formatting guidelines will result in a failure of the qualifying exam and the need to undertake a Master's defense before continuation in the Ph.D. program.

The exam date and time for each student will be scheduled by the Department's faculty Graduate Program Director in consultation with the faculty.

Both the oral presentation and the written document should provide succinct and clear descriptions of the concepts underlying the proposed dissertation research, the goals of the project, and the methods to be used in achieving those goals. While they may be incomplete, results obtained to date provide a useful focus for the exam. Questions asked by the faculty may address specific details or the broader context of the project presented, the proposed approaches, and associated chemical engineering principles. Clear communication in both the oral and written presentations and in interpreting and answering questions is essential to pass the exam.

In each student's preparation for the exam, the advisor is likely to be the principal source of information and guidance. However, since it is expected that both the written and the oral presentations represent the student's own work, **advisors do not work with the students on the structure or content of either the presentation or written document, e.g., by reading drafts of the written document or the slides, or being present during practice talks.**

In reaching a decision on admission to Ph.D. candidacy, the student's performance in the required first-year courses is also considered in addition to the oral exam. These courses provide perhaps the best view of each student's analytical skills. In recognition of the important role that course work plays in providing a good assessment of the analytical capabilities essential for successful completion of the Ph.D., in a situation in which a student does not meet the minimum grade requirements (i.e., receiving B- or lower grade in one or more core graduate courses), the department will consult with the dissertation advisor(s) on a case-by-case basis to determine the student's eligibility to take the qualifier exam before retaking any courses.

The faculty will also consider other information in addition to performance in the formal qualifying procedures in assessing the student's suitability for admission to Ph.D. candidacy. Course instructors and, most importantly, each student's advisor, because they have more opportunities for closer interactions, are expected to have informed perspectives on each student's comprehensive performance in the program.

The faculty, as a group, will make their decisions on admission into the Ph.D. program within a week after all the oral presentations have been completed. The decisions will be conveyed to the students in writing by the Department Chair. All of the components of the exam are equally important. A strong showing in only one area will probably not be sufficient to ensure admission into Ph.D. candidacy, but neither will a weak showing in any single area lead to automatic failure.

The faculty member in charge of each student's dissertation committee will provide a written summary of the faculty's feedback to the student within one week after candidacy decisions are completed. This summary will include strengths and weaknesses identified by the committee in the student's written report and oral exam, as well as recommendations regarding the student's goals and timeline for the coming year's research efforts.

The department admits students into its graduate program with the expectation that they will be successful in the qualifying procedures and matriculate into the Ph.D. program. Consequently, the qualifying procedures are an evaluation intended to be a constructive learning and training experience, and not a barrier to the student's overall educational and professional goals.

The outcomes of the qualifying examination are: pass; conditional pass; fail with the option to be reconsidered after completing a master's thesis; and fail. Students earning a pass matriculate into the PhD program. Conditional pass requires that a student meet with the examination committee within a short time window (normally six months) to present additional material or work to be considered. Failure to satisfy the subsequent reevaluation will constitute unsatisfactory progress towards completion of the degree and a change in doctoral student status. Students who fail with an option to pursue a master's thesis will complete a Master's degree requirements, including writing a Master's thesis, and will defend this thesis to the examination committee within one year. Students who fail the qualifying exam are expected to complete a coursework Master's degree.

Research

A graduate education is the development of the skills necessary to conduct and present independent research. The Ph.D. dissertation should demonstrate that the student has (1) acquired the skills necessary to conduct high-quality research, including the ability to think creatively and critically, and (2) completed a coherent piece of independent research that makes a meaningful contribution to engineering scholarship. The length of the actual dissertation, the number of associated publications, and the time required, will necessarily vary, depending on the abilities and effort of the student, the details of the project, and the philosophy of the dissertation advisor.

The department does not prescribe, *a priori*, how long any given student will remain in residence. However, the Ph.D. program is a transition period, one that provides students with an opportunity to expand their intellectual horizons, to learn how to conduct research, and to be creative. The transitional nature means that students should progress as rapidly as possible toward completion of all of the objectives and requirements of the Ph.D. degree. The following sections describe the policies and guidelines that have been established to assist the student in the selection, conduct, and completion of the doctoral dissertation.

Dissertation topic selection

The Department does not allow students to choose dissertation topics or advisors prior to arriving at Delaware. Since research is such a critical component of the graduate program, students need time to gather information about available projects, to clarify their own personal research interests, and to think carefully about their own long-term objectives. To start this process, a set of written descriptions of available projects (prepared by the faculty offering them) is provided to the students at the beginning of the fall semester. Over the course of the ensuing few weeks, each faculty member presents his or her projects in a 30-minute talk. Graduate students are expected to attend all dissertation topic presentations, even if they have no interest in that particular research area. These presentations are an ideal way to meet the faculty and to become exposed to the full range of chemical engineering research activities in the department and broader profession. Students should talk individually to faculty members and other graduate students to gain a more thorough understanding of possible research topics. Several meetings may be required to fulfill this objective, and students are even encouraged to work with the faculty to develop project ideas that match their personal research interests.

In early-to-mid November, students are required to provide a list of their advisor preferences and a paragraph describing their reasoning to the faculty Graduate Program Coordinator. This date can vary by a few weeks from year to year depending on funding or project availability as dictated by funding agencies.

The advisor-dissertation project preference list must include at least three unique proposed advisors. Matching students to research topics and advisors is a difficult constrained multivariable problem. Many factors are involved in the determination of the final assignments, including current research group sizes, faculty objectives, department objectives, funding, and student preferences. Often the final solution may not be a perfect match of student and preferred project. Nevertheless, the department is committed to finding the best possible solution, which might involve having some students meet again with the faculty Graduate

Program Coordinator and individual faculty to discuss options.

Dissertation committee

Research projects are carried out independently, but not in isolation. Graduate students are encouraged to involve faculty, both inside and outside the department. To foster such interactions, a formal structure for this interaction is provided in the form of a dissertation committee.

The dissertation committee consists of at least two other faculty members chosen by the student in consultation with the dissertation advisor; other Ph.D. holders (e.g., those working in industry or national laboratories) may also be included, as deemed appropriate. The faculty members of the committee will usually be from the Chemical and Biomolecular Engineering department, but outside faculty may also be included. However, the committee for the final dissertation defense must include one outside faculty member. This external member of the committee does not need to be identified prior to qualifying exams, but they must be included in subsequent committee meetings and decisions once a student has been admitted to Ph.D. candidacy. Additional committee members may be added at any time before the dissertation defense. However, removal of a committee member requires that the committee member in question give written approval to the department's faculty Graduate Program Coordinator, or else requires special approval from the Department Chair if the faculty member in question is unable or unwilling to fulfill his or her role as a committee member within a reasonable time frame.

The dissertation committee members make a commitment to provide input and feedback throughout the course of the dissertation research. This includes feedback on your departmental research presentations and during committee meetings. Students are strongly encouraged to provide the committee with written progress reports and copies of manuscripts and publications.

Several departmental requirements for formal interactions with the dissertation committee are described here. These interactions are intended to encourage flexibility and to ensure that substance, rather than form, prevails. However, the requirement of a minimal set of interactions is intended to help facilitate measurable progress toward degree completion at a reasonable pace, without stifling creativity and inhibiting the dissertation direction from evolving freely. **Each student is required to meet with his or her dissertation committee around the end the second year, prior to the start of the third year.** This is separate from the second year research talk presented to the department as a whole. The purpose of the meeting is for the student to present results and update the committee on progress made and any changes in direction since the qualifying exam. It is also intended to ensure that sufficient progress is being made to justify department funding commitments. Another committee meeting is required around the end of the fourth year, provided that the student has not already graduated. **A formal committee meeting is not required in the third year, but students must provide the committee members with a brief written summary as an update between the 2nd-year and 4th-year meetings.** The exact format is flexible. Students are encouraged to seek additional informal or formal feedback proactively from individual committee members as needed.

Department research symposia

Good presentation skills are necessary for the practice of good research. Participation in the departmental research symposia provides the student an opportunity to develop these skills. Each student is expected to present two symposia talks during his or her graduate studies: one during the 2nd year and another during the 4th year. These talks are given as part of a day-long Departmental Research Review that provides students, faculty, and postdocs an opportunity to learn about different research areas, discuss alternative approaches to research, and provide comments and feedback to colleagues.

The content of the talks will vary with the state of the projects, but a typical content will include background, experimental approach, results, and future plans. Typically, the second year talk is essentially a preliminary report and a research proposal; the fourth year talk is more polished, featuring a more coherent presentation of project results. The student can improve his or her skills by soliciting feedback from faculty members and other students; at a minimum each dissertation committee member should be consulted. Students are encouraged to make use of video equipment, which is available for recording and reviewing presentations.

Final dissertation defense

The final oral defense is a presentation of a summary of the completed research to the department, the defense committee, and the public research community. The defense committee may be the same as the dissertation committee discussed above, with the addition of one member from outside the department. The student must provide a copy of the dissertation to each member of the defense committee at least 2 weeks before the defense. At this time, the departmental Graduate Services Coordinator should also be informed of the date and venue of the defense, and an announcement, including an abstract, should be distributed to the department.

The period leading up to the final defense should involve close interaction of the student, the advisor, and the dissertation committee. Since a good research project is often open-ended, questions such as which specific goals are to be pursued and which are to be set aside as secondary require substantial discussion. To allow all possible points of view to be brought to bear on these issues, continuous involvement of the dissertation committee is recommended to obtain the best advice possible. Such involvement of several faculty also ensures good communication of progress and expectations, and that impartial reviews of any divergent views occur promptly. At a minimum, each student must hold a dissertation committee meeting no less than six months prior to the intended defense date. This meeting may preempt the 4th-year committee meeting requirement described above.

Funding

Funding will be available on a continuing basis provided the student maintains satisfactory progress toward completion of the degree. During the first year, the main criterion is that a 3.00 GPA must be maintained in course work throughout the program. After the first year, progress will primarily be in research, where a clear quantitative measure of performance is infeasible.

In general, the dissertation advisor is responsible for this progress review, but in cases where there is disagreement between advisor and student, the dissertation committee will provide an independent evaluation to determine if there is satisfactory progress for continuation of funding. In the event that progress is deemed unsatisfactory, the student will be provided at least three months of notice that funding is in danger of being discontinued, and, wherever possible, will be given sufficient opportunity to rectify the situation. Although the likelihood of this happening during the early stages of the research is slim, students should be aware that all dissertation projects must eventually end, and thus the likelihood of funding being discontinued increases with increasing residence time in the program. Funding is not guaranteed beyond four years.

The majority of students in the department are supported on research contracts, grants, and other funds obtained by their faculty advisors. Students on projects without external funding will be provided support (as long as their progress is satisfactory) using either departmental funds or by appointment as a teaching assistant. No student will be supported by departmental funds for more than five semesters; funds beyond such a commitment must be provided by the dissertation advisor or by appointment as a teaching assistant.

External fellowships

Ph.D. students who independently receive external fellowships that provide funding toward their stipend will have their standard graduate stipend supplemented by an amount equal to half the external fellowship amount or 1/3 of the regular Ph.D. graduate student stipend applicable at the time, whichever is smaller. Internal fellowships are considered to be those managed by the university (e.g. Delaware Space Grant Consortium), training grants, and fellowships and do not qualify for stipend supplements.

Teaching Assistants

The ability to communicate ideas, concepts, and factual information in any environment is an essential skill for all Ph.D. graduates, even those who have no interest in an academic position. Consequently, all Ph.D. students are required to fulfill a teaching requirement, which consists of serving as a TA for two lecture-style courses or for one Junior or one Senior laboratory course. Students who serve as a TA for a lab will be considered full-time TAs for that semester, while students who serve as a TA for a lecture will be considered half-time TAs. All TAs are expected to continue to be actively involved in their research while serving as a TA. Although the exact timing of TA appointments is flexible, it is highly desirable that students complete all TA responsibilities relatively quickly (by the end of the 3rd year if possible) to allow them to focus entirely on their research as they near the end of their graduate studies.

In order to be an effective TA, it is essential that students have adequate command of the English language. Graduate students considered deficient in language ability will be required to correct this deficiency, for example, by taking an appropriate course through the University's English Language Institute. Language deficiencies can also be identified during the Oral Qualifying Examination. Final decisions on how to resolve these deficiencies are made by the Graduate Program Coordinator in consultation with the student's dissertation advisors and the Department Chair.

Teaching Assistant positions are assigned by the faculty Graduate Program Coordinator in November (for the upcoming spring semester) and in May (for the following fall). Students are encouraged to submit their preferences for specific TA positions early to facilitate the process. Although every effort is made to satisfy these requests, this may not always be possible. **In addition, the educational needs of the Department may require the Graduate Program Coordinator to ask students to fill specific TA positions.**

Every spring, the Department recognizes the contributions of our most outstanding TAs with the Robert L. Pigford Awards for Outstanding Teaching Assistants. These awards, which include modest financial gifts, are used to acknowledge exceptional TAs for their efforts toward advancing the Department's educational mission.

Teaching Fellowships

The Department has established the Teaching Fellowship program for graduate students with particular interest in academic careers. Each Teaching Fellow co-teaches a Chemical Engineering course with a faculty mentor. The Fellow is involved in all aspects of the course (lecturing, preparation of new material, grading, assessment, etc.) Graduate students interested in the Teaching Fellow program should meet with the Graduate Program Coordinator to discuss the various options. Teaching Fellows are chosen by a committee based on their performance in previous TA positions, recommendations from their dissertation advisor, and comments from the prospective faculty mentor. It is strongly encouraged that students complete their TA requirements prior to applying for a Teaching Fellowship. The committee may award a particularly outstanding Teaching Fellow candidate the Shirley and Fraser Russell Teaching Fellowship.

Requirements for the MChE Degree

Students who obtain a MChE instead of a Ph.D. or who do not matriculate into the Ph.D. program have two options for graduate education leading to a Master's in Chemical Engineering (MChE) Degree.

The thesis option requires 6 credit hours of thesis work (CHEG869 Master's Dissertation) and 24 credit hours of course work; it is designed for full-time graduate students in residence. The course option requires 30 credits of course work and is designed for engineers who are studying part-time. The faculty member supervising the thesis research will act as an advisor for students in the thesis option. The Department's Graduate Program Director will act as an advisor to all students in the course work option.

Both options require 10 credits (five courses) of core courses in chemical engineering fundamentals: Modeling, Analysis, and Acquisition of Data (CHEG807, 2 credits); Molecular Thermodynamics (CHEG810, 2 credits); Kinetic Processes (CHEG820, 2 credits); Diffusive Transport Processes (CHEG821, 2 credits); and Chemical and Biomolecular Engineering Seminar (CHEG800, 1 credit, taken twice). Students must take an additional 4 credits of advanced engineering courses that includes Advanced Scientific Communication (CHEG803, 2 credits) and either Introduction to Data and Systems Analysis (CHEG802, 2 credits) or Chemical Interfaces and Surfaces (CHEG811, 2 credits).

All students are required to complete an additional four credits of advanced chemical engineering coursework that may take the form of a concentration. Concentrations consist of two 2-credit modules as defined below. Students opting to undertake a concentration must declare their concentration by the end of the Fall semester of their first year. Students who opt not to complete a concentration may meet the 4-credit additional coursework requirement by taking any combination of two additional 2-credit advanced chemical engineering modules.

<u>Biomolecular Concentration</u>
CHEG 840 Rate Processes & Dynamics for Microbial Systems (2 credits)
CHEG 843 Rate Processes & Dynamics for Mammalian Cellular Systems (2 credits)

<u>Catalysis and Energy Concentration</u>
CHEG 850 Electrochemical Processes (2 credits)
CHEG 851 Applied Thermodynamics (2 credits)

<u>Data and Systems Concentration</u>
CHEG 860 Process Systems Engineering: Mathematical Modeling and Optimization Principles (2 credits)
CHEG 861 Data Science for Chemical and Biomolecular Engineering (2 credits)

<u>Soft Matter Concentration</u>
CHEG 830 Continuum Transport in Materials (2 credits)
CHEG 832 Soft Materials, Colloids, and Polymers (2 credits)

<u>No Concentration</u>
Any combination of two 2-credit modules of advanced chemical engineering coursework not otherwise counted towards the student's core course requirements.

Sample trajectories for the graduate coursework as well as short course descriptions for core courses and concentration modules are provided in **Appendix B**.

In addition, the Department offers numerous technical electives in all areas of Chemical Engineering, and up to six credits of technical electives may be taken in suitable courses outside Chemical Engineering.

Continued funding is provided only for MChE students pursuing the thesis option. Students who have been provided support will generally not be allowed to pursue the non-thesis MChE degree. Funding will be available for students performing MChE thesis work on a continuing basis if they maintain satisfactory progress towards the degree. A 3.00 GPA must be maintained throughout the program. Students should be aware that theses must come to an end in a reasonable period of time (typically 18 months). Funding beyond the 18-month period is not guaranteed.

APPENDIX A

Overview of formal requirements & milestones for progression of Ph.D. candidacy

YEAR 1: Fall: Take core classes and elective(s) and undergo advisor selection process
YEAR 1: Spring: Start research in assigned research lab, take core and elective classes
YEAR 1: Summer: Identify faculty members in the department who will serve as Ph.D. committee.
YEAR 1: August: Qualifying Exams
YEAR 2: Fall: Identify external dissertation committee member once admitted to candidacy.
YEAR 2: Summer: Participate in 2nd year talk
YEAR 3: Prior to start of Year 3, set up a FORMAL committee meeting with your dissertation committee. Another informal update to the committee is expected during the third year.
*** Complete 2 semesters of teaching assistantship (preferably in YEAR 2 or 3)*
YEAR 4: Winter: Participate in 4th year talk
YEAR 4-5: Set up a penultimate committee meeting ~6 months before final defense, Complete final defense

APPENDIX B – Example Curricula and Short Course Descriptions

Sample Curriculum 1: Ph.D. in Chemical Engineering with Biomolecular Concentration (Soft Materials Option in FALL II)

FALL I
CHEG 807 Modeling, Analysis, and Acquisition of Data (2 credits)
CHEG 810 Molecular Thermodynamics (2 credits)
CHEG 820 Kinetic Processes (2 credits)

FALL II
CHEG 811 Chemical Interfaces and Surfaces (2 credits)
CHEG 821 Diffusive Transport Processes (2 credits)

FALL (REGULAR)
CHEG 800 Chemical and Biomolecular Engineering Seminar (1 credit)
CHEG 6xx/8xx Technical Elective

SPRING I
CHEG 803 Advanced Scientific Communication (2 credits)
CHEG 840 Rate Processes & Dynamics for Microbial Systems (2 credits)

SPRING II
CHEG 843 Rate Processes & Dynamics for Mammalian Cellular Systems (2 credits)

SPRING (REGULAR)
CHEG 6xx/8xx Technical Elective

Sample Curriculum 2: Ph.D. in Chemical Engineering with Biomolecular Concentration (Data and Systems Option in FALL II)

FALL I
CHEG 807 Modeling, Analysis, and Acquisition of Data (2 credits)
CHEG 810 Molecular Thermodynamics (2 credits)
CHEG 820 Kinetic Processes (2 credits)

FALL II
CHEG 802 Introduction to Data and Systems Analysis (2 credits)
CHEG 821 Diffusive Transport Processes (2 credits)

FALL (REGULAR)
CHEG 800 Chemical and Biomolecular Engineering Seminar (1 credit)
CHEG 6xx/8xx Technical Elective

SPRING I
CHEG 803 Advanced Scientific Communication (2 credits)
CHEG 840 Rate Processes & Dynamics for Microbial Systems (2 credits)

SPRING II
CHEG 843 Rate Processes & Dynamics for Mammalian Cellular Systems (2 credits)

SPRING (REGULAR)
CHEG 6xx/8xx Technical Elective

Sample Curriculum 3: Ph.D. in Chemical Engineering (no concentration)

FALL I
CHEG 807 Modeling, Analysis, and Acquisition of Data (2 credits)
CHEG 810 Molecular Thermodynamics (2 credits)
CHEG 820 Kinetic Processes (2 credits)

FALL II
CHEG 802 Introduction to Data and Systems Analysis (2 credits)
CHEG 811 Chemical Interfaces and Surfaces (2 credits)
CHEG 821 Diffusive Transport Processes (2 credits)

FALL (REGULAR)
CHEG 800 Chemical and Biomolecular Engineering Seminar (1 credit)
CHEG 6xx/8xx Technical Elective

SPRING I
CHEG 803 Advanced Scientific Communication (2 credits)

SPRING II
CHEG 843 Rate Processes & Dynamics for Mammalian Cellular Systems (2 credits)

SPRING (REGULAR)
CHEG 6xx/8xx Technical Elective

Sample Curriculum 4: Ph.D. in Chemical Engineering (no concentration; Data and Systems Option in FALL II)

FALL I
CHEG 807 Modeling, Analysis, and Acquisition of Data (2 credits)
CHEG 810 Molecular Thermodynamics (2 credits)
CHEG 820 Kinetic Processes (2 credits)

FALL II
CHEG 802 Introduction to Data and Systems Analysis (2 credits)
CHEG 821 Diffusive Transport Processes (2 credits)

FALL (REGULAR)
CHEG 800 Chemical and Biomolecular Engineering Seminar (1 credit)
CHEG 6xx/8xx Technical Elective

SPRING I
CHEG 803 Advanced Scientific Communication (2 credits)
CHEG 840 Rate Processes & Dynamics for Microbial Systems (2 credits)

SPRING II
CHEG 861 Data Science for Chemical and Biomolecular Engineering (2 credits)

SPRING (REGULAR)
CHEG 6xx/8xx Technical Elective

Short course descriptions

CHEG 807 Modeling, Analysis, and Acquisition of Data (2 credits). Provides a fundamental understanding of uncertainty in data to facilitate efficient data analysis and data acquisition. Topics include Probability as a fundamental tool for modeling and rigorous analysis of randomly varying phenomena; Statistics, as a complement to probability, for efficiently describing and extracting information contained in data, to enable confident data-based decision-making; and Design of Experiment, as a coherent collection of strategies for systematically acquiring informative data.

CHEG 810 Molecular Thermodynamics (2 credits). Introduction to statistical thermodynamics of molecular systems. Topics include ensembles and partition functions; monatomic and polyatomic gases; intermolecular potentials; monatomic crystals; lattice models; liquid-state theory; integral equation theories; perturbation theory; computer simulation.

CHEG 820 Kinetic Processes (2 credits). Students will learn to think about chemical reactions at a multi-scale level: from molecular to macroscopic. They will integrate molecular theories of reaction rates within complex reaction networks and develop simplified kinetic models that describe physical and biological systems of engineering and scientific interest.

CHEG 802 Introduction to Data and Systems Analysis (2 credits). To introduce basic linear algebra principles and the underlying minimum mathematical and numerical concepts necessary to modern Chemical Engineering research, from the analysis of experimental data, to the handling of big data and mathematical modeling and simulations.

CHEG 832 Soft Materials, Colloids, and Polymers (2 credits). Integration of continuum and molecular descriptions of matter are the basis for engineering soft materials. Topics of this course will include polymer dynamics; rubber elasticity theory; stability and phase transitions; colloidal stability; scattering methods in soft materials; protein interactions; polyelectrolytes; polymer adsorption; glasses and gels.

CHEG 821 Diffusive Transport Processes (2 credits). This course develops a conceptual understanding of diffusive transport processes ranging from simple molecular models of transport in gases and liquids to macroscopic processes. Methods to formulate, simplify and develop approximate solutions to transport problems are presented. These approaches are used as a basis to understand transport in complex materials such as polymers, porous catalysts, ionic solutions and biological tissues.

CHEG 803 Advanced Scientific Communication (2 credits). Written and oral communication skills in science and engineering. Topics include evaluating the audience, creating documents and presentations with scientific clarity, persuasive writing and speaking, applying constructive editing, and communicating effectively using in-person and online platforms.

CHEG 800 Chemical and Biomolecular Engineering Seminar (1 credit). Responsible and effective research practices in Chemical and Biomolecular Engineering. Topics include expectations in graduate school, the graduate student-advisor relationship, work-life balance and self-care, time management, teamwork and collaboration, mentor-mentee relationships, goal setting and prioritization, planning the career transition, self-advocacy, and becoming a leader.

CHEG 840 Rate Processes & Dynamics for Microbial Systems (2 credits). Analysis of microbial systems. Topics include enzyme reactions, transcription and translation, gene regulation, flux analysis, cell growth, stochastic networks and oscillatory behaviors, chemotaxis, and quorum sensing.

CHEG 843 Rate Processes & Dynamics for Mammalian Cellular Systems (2 credits). Analysis of mammalian cellular systems. Topics include cell signaling, cell proliferation and growth, cell adhesion and migration, cell phenotype and function, collective/multicellular processes including considerations of specific tissues and applications in biotechnology, and engineering approaches in controlling these cellular processes as well as quantitative analysis of key time and size scales.

CHEG 850 Electrochemical Processes (2 credits). This course covers the fundamental concepts and principles of electrochemistry, including electrochemical thermodynamics, electrokinetics, transport, the electrochemical interface, and electroanalytical techniques (e.g., cyclic voltammetry, electrochemical impedance spectroscopy, and polarization).

CHEG 851 Applied Thermodynamics (2 credits). This course covers a review and applications of the basic principles of continuum thermodynamics, including interpretation using molecular and statistical thermodynamics. Applications emphasize the relevance of energy and entropy balances to contemporary problems including energy conversion in biological and non-biological systems as well as the characteristics of phase separation in synthesizing specialized materials.

CHEG 860 Process Systems Engineering: Mathematical Modeling and Optimization Principles (2 credits). Provides instruction on the mathematical programming techniques used in the solution of process design, and operations problems. Educate students to structure and solve complex problems and integrate material from diverse range of engineering disciplines - a systems approach to problem solving. Topics include mathematical programming techniques, foundation of process optimization involving linear, nonlinear and mixed integer problems, sensitivity analysis, feasibility evaluation to incorporate the effects of uncertainty, stochastic optimization, surrogate model building, simulation based and multi-objective optimization.

CHEG 861 Data Science for Chemical and Biomolecular Engineering (2 credits). This course builds upon the introduction to data science and probability and statistics courses to provide advanced coverage of small and big data applications and methods. It uses Python and different software tools to integrate theory and computation of data science methods applied to the chemical and biomolecular engineering domain.

CHEG 811 Chemical Interfaces and Surfaces (2 credits). Principles of the chemistry of interfaces and surfaces. Topics include: Surface forces; electrolyte solutions and Poisson-Boltzmann theory; van der Waals forces; Lifshitz theory; physisorption and chemisorption; adhesion and wetting phenomena; friction and lubrication; force-measuring techniques.

CHEG 830 Continuum Transport in Materials (2 credits). Continuum mechanics of fluids and solids; low and high-Reynolds number flows; boundary layer theory; microhydrodynamics and creeping flows; scaling and asymptotic analysis; electrokinetics; convective mass transfer.